NON-FERROUS SMELTERS:
ACID PLANT SCRUBBERS
(MARCH, 1984)

BY

Fenco Engineers Inc.

FOR

Environmental Protection Service
Environment Canada

This report has not undergone detailed technical review by the Environmental Protection Service and the content does not necessarily reflect the views and policies of Environment Canada. Mention of trade names or commercial products does not constitute endorsement for use.

This unedited version is undergoing a limited distribution to transfer the information to people working in related studies. This distribution is not intended to signify publication and, if the report is referenced, the author should cite it as an unpublished report of the Environmental Protection Service.

Any comments concerning its content should be directed to:

Dr. L. Buffa
Industrial Programs Branch
Environmental Protection Programs Directorate
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

IP-24
January 1985

STUDY AND REPORT ON THE NON-FERROUS SMELTERS: ACID PLANT SCRUBBERS

FOR

SUPPLY AND SERVICES CANADA

S&S CONTRACT NO. 47SS KE145-3-0255/0SS83-0015

35324
MARCH 1984

EXECUTIVE SUMMARY

This preliminary study describes the general characteristics and costs of gas cleaning and effluent treatment facilities for the removal of contaminants from non-ferrous smelter gases. Three types of gases, containing a range of impurities, and three levels of sulphuric acid production are analyzed. Order-of-magnitude operating costs (including annualized capital) range from five to nine dollars per tonne of acid, depending on production level and concentrate characteristics.

The study also finds that a substantial quantity of contaminated sludge would be produced, requiring additional costs to provide secure long term storage.

On the other hand, acid quality and stack emissions are likely to be acceptable. Product acid contains less than one ppm of each impurity in all cases, and less than 0.1 percent of any contaminant passes through to the acid plant stack.

TABLE OF CONTENTS

		Page #
	EXECUTIVE SUMMARY	
1.0	SUMMARY AND DISCUSSIONS	1-1
2.0	INTRODUCTION	2-1
3.0	DESCRIPTION OF SCRUBBER PERFORMANCE ON IMPURITY ELEMENTS	3-1
4.0	SCRUBBERS IN CANADA	4-1
5.0	SCRUBBER EFFLUENT TREATMENT	5-1
6.0	COSTS - CAPITAL AND OPERATING	6-1
7.0	ACID QUALITY AND CONTAMINANT REMOVAL	7-1
8.0	CONCLUSIONS	8-1
9.0	REFERENCES	9-1

APPENDIX A - SCRUBBER DESIGN REFERENCES

APPENDIX B - NORTH AMERICAN NON-FERROUS SMELTER ACID COMPOSITIONS

APPENDIX C - HOT ELECTROSTATIC PRECIPITATOR PERFORMANCE

LIST OF TABLES AND FIGURES

Reference #	Title
Table 1.1.1	Impurity Concentrations in Acid Plant In-coming Gas and Product Acid
Table 1.1.2	Effluents Produced during Gas Cleaning
Table 1.1.3	Approximate Capital and Annual Operating Costs
Table 3.1.1	Calculated Concentrate Compositions
Figure 3.2.1	Clean Copper Concentrate, Case I: Element Distribution in a Flash Smelting Circuit
Table 3.2.2	Clean Copper Concentrate, Case I: Materials Balance
Figure 3.2.3	Moderately Dirty Concentrate, Case II: Element Distribution in a Flash Smelting Circuit
Table 3.2.3	Moderately Dirty Concentrate, Case II: Materials Balance
Figure 3.2.4	Dirty Copper Concentrate, Case III: Element Distribution in a Flash Smelting Circuit
Table 3.2.4	Dirty Concentrate, Case III: Materials Balance
Table 3.2.5A	Gas Impurity Concentrations After Coarse Dust Removal - Design and Case Examples

LIST OF TABLES AND FIGURES (cont'd)

Reference #	Title
Table 3.2.5B	Upper Impurity Limits for Cleaned Smelter Gas After Gas Cleaning and Conditioning.
Figure 3.3.2	Case I: Gas Cleaning and Effluent Treatment Block Diagram.
Table 3.3.2	Clean Concentrate, Case I: Acid Plant Materials Balance
Figure 3.3.3	Case II: Gas Cleaning and Effluent Treatment Block Diagram
Table 3.3.3	Moderately Dirty Concentrate, Case II: Acid Plant Materials Balance
Figure 3.3.4	Case III - Gas Cleaning and Effluent Treatment Block Diagram
Table 3.3.4	Dirty Concentrate Case III: Acid Plant Materials Balance
Table 3.3.5	Upper Impurity Limits for Cleaned Smelter Gas After Gas Cleaning and Conditioning
Table 4.2.1	Summary of Canadian Metallurgical Gas Cleaning Operatings Preceeding Sulphuric Acid Production
Table 4.6.1	Canadian Metallurgical Operations: Summary of Effluents Produced during Scrubbing and Their Disposal

LIST OF TABLES AND FIGURES (cont'd)

Reference #	Title
Table 5.1.1	Selected Guidelines for Water Quality Parameters
Table 5.2.1	Summary of Feeds to Scrubber Effluent Treatment Systems
Figure 5.2.2-1	Case I: Effluent Treatment Flowsheet
Figure 5.2.2-2	Case II: Effluent Treatment Flowsheet
Figure 5.2.2-3	Case III: Effluent Treatment Flowsheet
Table 6.2.1	Summary of Capital Costs for Scrubbing and Effluent Treatment for Case I - Clean Concentrate
Table 6.3.1	Summary of Capital Costs for Gas Cleaning and Effluent Treatment Plant Areas for Case II - Moderately Dirty Concentrate
Table 6.4.1	Capital Costs Summary for Gas Cleaning and Effluent Treatment Plant Areas for Case III - Dirty Concentrate
Table 6.5.1-1	Case I: Summary of Annual Direct Operating Costs
Table 6.5.1-2	Case II: Summary of Annual Direct Operating Costs
Table 6.5.1-3	Case III: Summary of Annual Direct Operating Costs
Table 7.1.1	Summary of Typical Acid Quality (Contaminant) Specifications

LIST OF TABLES AND FIGURES (cont'd)

Reference #	Title
Table 7.2.1	Summary of Acid Quality and Contaminant Removal
Table B-1	American Non-Ferrous Smelter Sulphuric Acid Analyses
Table C-1	Summary of Impurity Element Recoveries in Hot Electrostatic Precipitator

SECTION 1

SUMMARY AND DISCUSSION

1.0 SUMMARY AND DISCUSSION

Production of sulphuric acid from non-ferrous smelter gases requires removal of over 99 percent of the incoming dust and fume contaminants to minimize fouling of the catalyst pellet bed and contamination of the product acid. Impurities in the process gas are transferred to the liquor effluent produced in the gas cleaning section of the acid plant. The effluent slurry is an acidic solution bearing a variety of heavy metals and as such requires treatment and careful disposal.

This study, sponsored by Environment Canada and commissioned by the Federal Department of Supply and Services, reviews the scrubber literature and lists references, reviews the generic performance of scrubbers related to removal of contaminants, reviews Canadian scrubbing operations, outlines effluent treatment systems, develops capital and operating costs for gas cleaning and effluent treatment systems, and discusses sulphuric acid contamination and acid plant stack emissions.

Three concentrates, containing a range of quantities of contaminants are assumed to be processed at three rates each in a flash furnace - Peirce-Smith converter operation. The levels of contaminants in the resulting calculated acid plant gas feeds are compared in Table 1.1.1 with approximate limits for standard low-cost scrubbers. More expensive scrubbers are required for processing the higher levels of contaminants in Case III.

Product acid contains less than one ppm of each impurity in all cases. Available acid plant operating data show similar acid contamination levels. All of the acids can be used in the production of fertilizer.

TABLE 1.1.1

IMPURITY CONCENTRATIONS IN ACID PLANT
IN-COMING GAS AND PRODUCT ACID

Impurity	Calculated Gas Impurities mg/Nm^3			Approx. Inlet Design Limit mg/Nm^3	Estimated Product Acid Impurities (ppm)		
	Clean Concentrate Case I	Moderately Dirty Concentrate Case II	Dirty Concentrate Case III		Case I	Case II	Case III
Pb	6.3	82.1	303	200	<0.1	0.1	0.5
Cd	-	-	0.004	*	-	-	<0.1
As_2O_3	3.5	249	274	200	<0.1	0.4	0.5
Hg	0.015	0.31	31.2	2.5	<0.1	0.1	0.39
Se	5.9	40.1	58	100	<0.1	0.4	0.8
Dust	200	200	200	1000	-	-	-
F	18	23	46	25	<0.1	0.1	0.4
Cl	20	20	20	125	<0.1	0.1	0.1
Zn	8.5	98	95	*	<0.1	<0.1	0.2

*included in dust

Less than 0.1 percent of any contaminant passes through to the acid plant stack.

Effluents from the gas cleaning section of the acid plants are treated with lime and conditioners to remove metal constituents. The resulting mixture can be disposed of in a variety of ways, such as:

i) routing combined neutralized effluent to a conventional tailings area;

ii) initial precipitation of gypsum, followed by precipitation of contaminated sludge for secure storage; disposal of the neutralized liquid effluent with mill tailings;

iii) as in ii), but further processing of neutralized solid-free liquid effluent prior to disposal.

Table 1.1.2 outlines the estimated gas cleaning effluents produced at one level for the three cases examined. Over 90 percent of the metals in the scrubber effluents is expected to be in the precipitated solids.

Capital and operating costs for the gas cleaning and effluent treatment plant areas are summarized in Table 1.1.3.

A considerable quantity of contaminants are removed during gas cleaning, and the associated capital and operating costs for the scrubbing and effluent treatment plants are significant. The amounts of potentially hazardous sludges are sufficiently high to warrant a detailed investigation of secure disposal methods. This

TABLE 1.1.2

EFFLUENTS PRODUCED DURING GAS CLEANING

kg/day Streams and Contaminants	EFFLUENT PLANT FEEDS		
	Case I	Case II	Case III
Solids (dry)	425	1,935	2,888
Water	760,320	944,640	327,300
Pb	20	259	957
Zn	27	308	299
As	8.4	597	657
Hg	0.03	0.6	64.
Se	18	125	180
F	57	71	142
Cl	62	62	62
Cd	-	-	1.4

TABLE 1.1.3

APPROXIMATE CAPITAL AND ANNUAL OPERATING COSTS

Sulphuric Acid Production mtpd	Thousands $					
	Case I		Case II		Case III	
	Operating	Capital	Operating	Capital	Operating	Capital
600	845	3,556	1,083	4,770	1,141	6,230
1000	1,356	4,754	1,515	6,482	1,594	8,459
1500	1,708	5,989	2,052	8,243	2,184	11,539

is required because of the active state of the various contaminants and the need to find a safe, very long term solution. Similarly, the need for producing clear aqueous effluents for unrestricted discharge should be determined.

As noted above, less than 0.1 percent of any contaminant passes through to the acid plant stack. Nevertheless, the ultimate dispersion and impact of these should be evaluated in detail because the installation of the (acid plant) facilities must also result in a safe long term solution to the atmospheric dispertion of such contaminants.

The operating costs for scrubbing and effluent treatment are substantial (even without the cost of securely containing the sludge). These are in the order of five to nine dollars per tonne of acid (including annualized capital charge). This is of concern because the viability of reducing sulphur dioxide emissions is dependent on making this product at a low cost. There is considerable merit, therefore, in further investigating the factors which influence these costs and determining which combination of parameters are most economical. Concentrate characteristics are obviously important but the choice of smelting processes and technical operating parameters can influence volatilization substantially, which in turn affects operating costs. The quantity and size of particulates in the acid plant feed gas significantly affects power, a substantial part of the total operating costs.

Another major cost component is for the lime required to neutralize sulphuric acid vapour in the acid plant feed gas. However, the information available is not accurate because of the extreme variability of this constituent and the difficulty in developing a satisfactory analytical technique.

SECTION 2

INTRODUCTION

2.0 INTRODUCTION

Fenco Engineers Inc. was contracted by the Federal Department of Supply and Services to carry out a study dealing with the pollution potential associated with scrubbing of non-ferrous smelter gases during the production of sulphuric acid. The contract number assigned was 47SS KE145-3-0255/05583-00105.

The work was divided into five tasks as follows:

i) A literature review of scrubbers used to remove contaminants from flue gases.

ii) A review of scrubbers operating in Canadian non-ferrous smelters.

iii) A generic description and characteristics of scrubbers treating gases produced during smelting of a clean concentrate, a concentrate containing some lead, mercury, and arsenic, and a concentrate containing high concentrations of arsenic, and/or mercury, and some lead.

iv) A generic description and characteristics of effluent treatment plants associated with the gases described in Task iii.

v) Development of costs (capital and operating) for scrubbers and effluent treatment plants for each of flue gases in Task iii for acid plants producing 600, 1,000 and 1,500 mtpd of sulphuric acid.

vi) Estimates of the concentrations of contaminants in acid and comparisons of these with fertilizer grade acid. Where impurity concentrations exceed the specification, processes, including costs, to treat the acid to meet the specifications are described. Estimates of the concentration of contaminants in the sulphuric acid plant flue gas.

This report contains the results of the investigations and process calculations dealing with the tasks outlined above.

SECTION 3

DESCRIPTION OF SCRUBBER PERFORMANCE ON IMPURITY ELEMENTS

3.0 DESCRIPTION OF SCRUBBER PERFORMANCE ON IMPURITY ELEMENTS

3.1 Summary of Impurity Elements Contents of Concentrates Typical of Canadian Non-Ferrous Smelting Operations

Canadian non-ferrous smelting operations process a wide variety of concentrates. These range from low impurity materials typical of the Sudbury District to those bearing signficant concentrations of contaminants. A summary of three copper concentrate compositions used in this project, including trace elements, is shown in Table 3.1.1. The three compositions outlined exemplify clean, slightly dirty, and dirty concentrates. The three compositions are referenced as Case I, Case II and Case III respectively in the text. For the purpose of this study it is intended that the concentrate compositions used reflect the general range of composition observed across the country and should not be considered site specific.

Also shown in Table 3.1.1 are the mineralogical balances calculated for the three concentrate examples. These are consistent with the smelter material balances in Section 3.2. The mineralogical balancing was simplified by assuming iron sulphides are present only as pyrrhotite ($FeS_{1.14}$).

3.2 Smelter Operations & Balances Used to Estimate Compositions of Acid Plant Scrubber Feed Gases

3.2.1 General Approach

Gases produced during smelting or roasting of sulphides contain a variety of gaseous, fume, and particulate species. Therefore a number of gas cleaning steps are required prior to conversion of the SO_2 in the gas to sulphuric acid. Also, a minimum gas strength of 5% SO_2 is typically required for an auto-thermal operation.

TABLE 3.1.1. CALCULATED CONCENTRATE COMPOSITIONS

MATERIAL	mtpd	ASSAY WT. %					ASSAY ppm				mtpd				kg/d					
		Cu S	Fe	Zn	Pb	As	Hg	Se	Cd	Cl F	Cu S	Fe	Zn	Pb	As	Hg	Se	Cd	Cl	F
ASE I	1000	28 32	30	0.17	0.05	0.001	0.05	40	-	200 80	280 320	300	1.7	0.5	10	0.05	40	-	200	80
ASE II	1000	25.5 32	29	4.	1.7	0.09	1.0	700	-	200 100	255 320	290	40	17	900	1.	700	-	200	100
ASE III	1000	24 30	28	4.	6.	0.1	100	1000	100	200 200	240 300	280	40	60	10,000	100	1000	100	200	200
		WT. %									mtpd									
		Cp	Po	AsPy	ZnS	PbS	HgS	SeS	CdS	Other	Cp	Po	AsPy	ZnS	PbS	HgS	SeS	CdS	Other	
ASE I	1000	80.9	9.1	0.02	0.25	0.06	6×10^{-7}	0.006	-	9.6	809 3	90.9	0.22	2.53	0.58	6×10^{-9}	0.06	-	96.4	
ASE II	1000	73.7	9.9	0.2	5.97	1.96	0.0031	0.098	-	8.21	737	98.6	1.96	59.7	19.6	0.0012	0.98	-	82.1	
ASE III	1000	69.4	5.92	2.17	5.97	6.93	0.01	0.14	0.01	9.5	693.6	59.2	21.7	59.7	69.3	0.12	1.4	0.10	95	

Cp = chalcopyrite
Po = pyrrhotite
AsPy = arsenopyrite

To illustrate this process, a flowsheet was constructed showing the flow of gas, fume and dust in a smelter utilizing flash smelting and conventional Peirce-Smith converting. Flash smelting was selected due to current trends towards this form of processing and the availability of process data.

Examination of other smelting processes is outside the scope of the present work.

Figure 3.2.1 shows the basic smelting circuit assumed for the three concentrates described in Section 3.1. Matte from the flash furnace is processed to blister copper in classical Peirce-Smith converters. Gases from the flash furnace and converters are cleaned in cyclones and combined for final hot cleaning in an electrostatic precipitator (E.S.P.).

Dust recovered in the cyclones and E.S.P. are recycled to the flash furnace in Case I.

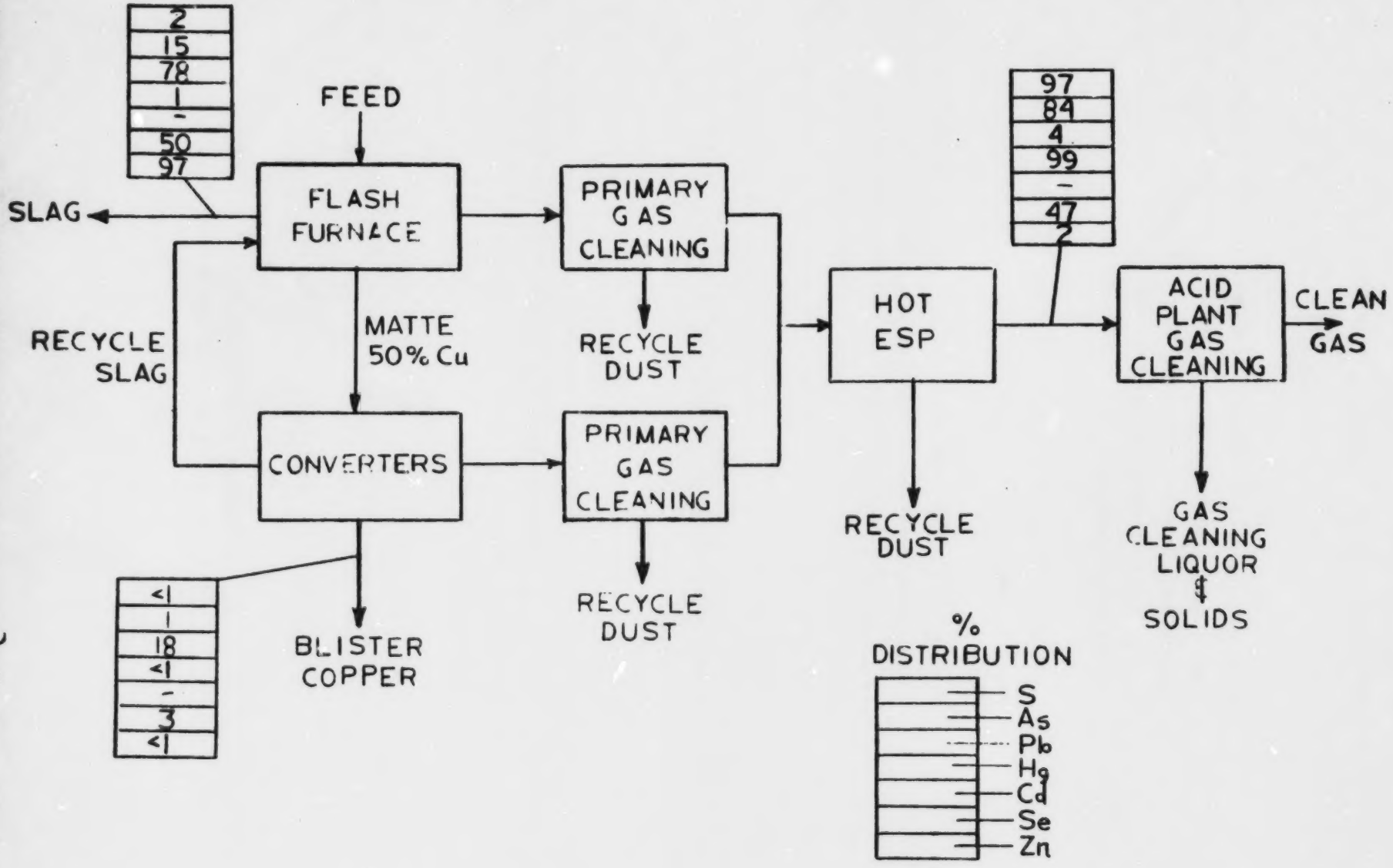
However, in Cases II and III, dust captured in the E.S.P. must be processed separately, to keep certain impurity elements from concentrating during recycling and contaminating the blister copper. This is a typical requirement of smelters processing concentrates containing large amounts of contaminants.

The concentrate assays used in the study incorporate published data supported where necessary by estimates based on Fenco's experience.

Material balances for the contaminants are based on:

i) a known degree of volatilization for each contaminant during primary smelting and a second during converting;

FIG. 3·2·1 CLEAN COPPER CONCENTRATE CASE I
ELEMENT DISTRIBUTION IN A FLASH SMELTING CIRCUIT



ii) a known distribution between matte and slag during primary smelting for each contaminant and a second during converting;

iii) recycle of all converter slag to the flash furnace.

3.2.2 Case I - Clean Concentrate Smelter Balance

Figure 3.2.1 shows the distribution of various elements around the smelting/converting/gas cleaning circuit treating the clean concentrate. Gas and dust escaping the E.S.P. are routed to the gas cleaning section of the acid plant. Gases, fume, and dust recoveries expected in the E.S.P. are outlined in Appendix C. A supporting materials balance is shown in Table 3.2.1.

Distributions of the gases, dust and fume within the gas cleaning section of the acid plant are discussed in Section 3.3.

3.2.3 Case II - Moderately Dirty Concentrate Smelting Distribution

Figure 3.2.3 outlines the distribution of various elements in the smelter treating the Case II moderately dirty concentrates.

The supporting materials balance is shown in Table 3.2.3.

3.2.4 Case III - Dirty Concentrate Smelting Distribution

Figure 3.2.4 outlines the distribution of various elements in the smelter treating Case III dirty concentrates. The supporting materials balance is shown in Table 3.2.4.

TABLE 3.2.2. CLEAN CONCENTRATE: CASE I MATERIALS BALANCE

	MATERIAL	mtpd	ASSAY WT. %									mtpd									
			Cu	Fe	S	SiO_2	Pb	Zn	As	Se	F	Cu	Fe	S	SiO_2	Pb	Zn	As	Se	F	Cl
Input:	Cu Conc.	1000	28	30	32	6.5	0.05	0.17	0.001	0.004	0.008	280	300	320	65	0.5	1.7	0.01	0.04	0.08	0.
	Flux	108				80						-	-	-	86.1	-	-	-	-	-	
	Converter Slag	260	48	51.1	1.9	24.2						12	113	4.8	6.3	0.56	0.55	-	-	-	-
	Recycle Dust											-	-	-	-	0.66	1.13	0.01	0.048		
	Total											292	413	324.8	214.1	1.7	3.38	0.02	0.088	0.08	0.
Out :	Matte	572	50	23.3	23	-	0.15	0.20	0.0007	0.001	0.001	286	133.5	131.6	-	0.84	1.15	0.004	0.006	0.006	0.
	Slag	647	0.7	43	1.5	33	0.06	0.26	0.0003	0.003		4.5	278	9.7	213.5	0.39	1.68	0.002	0.02	0.02	0.1
	ESP Inlet Dust											1.5	1.5	2.4	0.6	0.46	0.55	0.009	0.044	0.054	0.0
	Offgas											-	-	181.1	-	-				-	-
	Total												413	324.8	214.1	1.7	3.38	0.02	0.08	0.08	0.2
Input:	Con. Matte	572	50	23.3	23	-	0.15	0.21	0.000		0.001	286	133.5	131.6	-	0.84	1.15	0.004	0.005	.006	0.0
	Flux	79	-	-	-	80	-	-	-	-	-	-	-	-	63.2	-	-	-	-	-	-
Out:	Blister	277.7	98.5	-	-	-	0.0008			-	-	273.5	-	-	-	0.09	0.017	0.0001	0.0015	-	0.0
	Slag	260	4.8	51.2	1.9	24.2		-	-	-	-	12	133	4.8	63	0.56	0.55	-	.000	-	.0C
	ESP Inlet Dust	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.8	0.2	0.20	0.58	0.0029	0.004	0.005	0.01
	Off	-	-	-	-	-	-	-	-	-	-			12.6							
	Total											286	133.5	131.6	63.2	0.84	1.15	0.004	0.006	0.006	.02
Total ESP Inlet Dust												2.0	2.0	3.2	0.8	0.66	1.13	0.01	0.048	0.059	0.0
	Acid Plant Input											0.04	0.04	0.06	0.016	0.02	0.034	0.0084	0.019	0.058	0.0

FIG. 3·2·3 MODERATELY DIRTY CONCENTRATE CASE II
ELEMENT DISTRIBUTION IN A FLASH SMELTING CIRCUIT

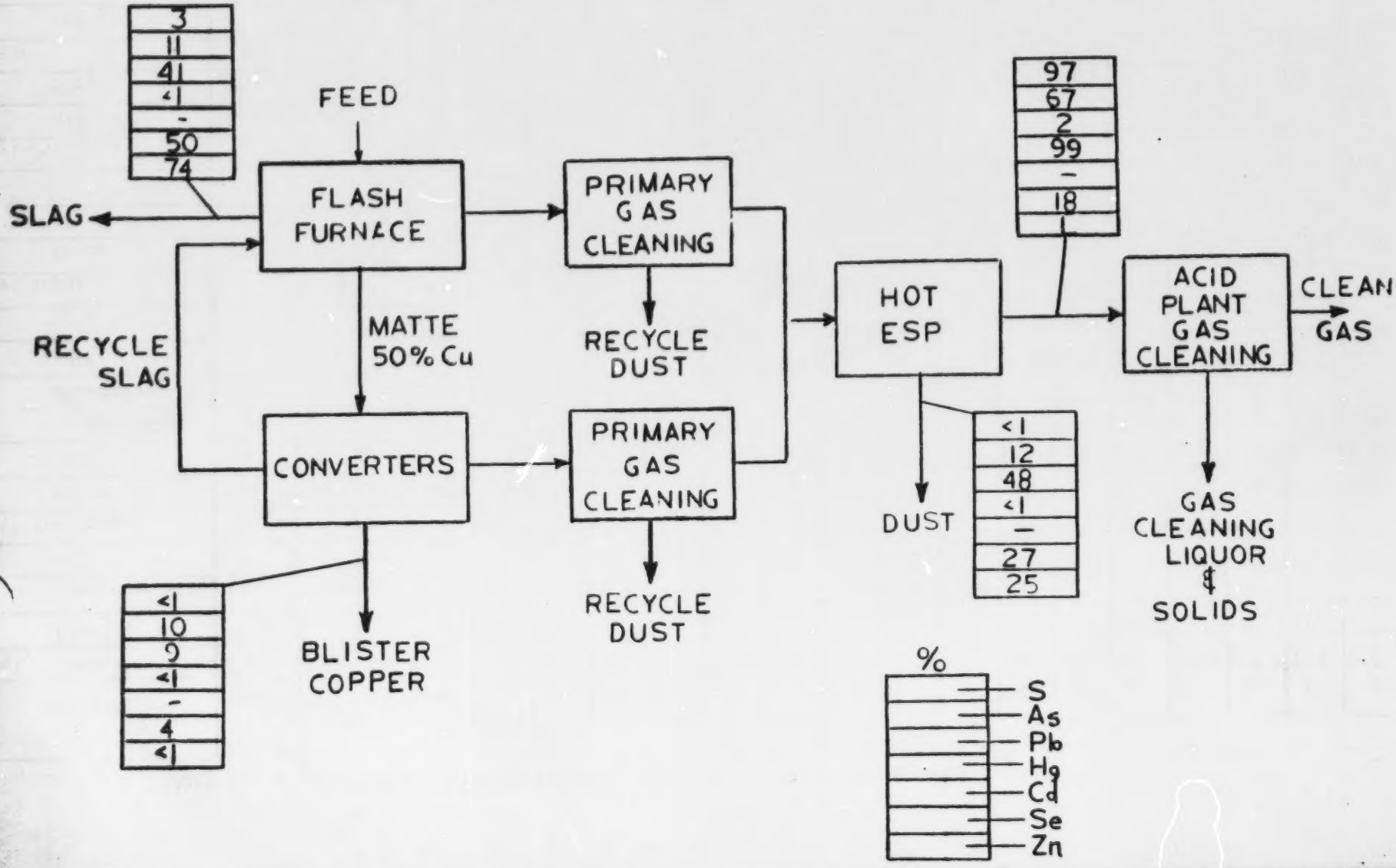


TABLE 3.2.3. MODERATELY DIRTY CONCENTRATE: CASE II MATERIALS BALANCE

MATERIAL			ASSAY WT. %									mtpd									
		mtpd	Cu	Fe	S	SiO_2	Pb	Zn	As	Se	F	Cu	Fe	S	SiO_2	Pb	Zn	As	Se	F	Cl
nput:	Concentrate	1000	25.5	29	32	6.5	1.7	4.	0.09	0.07	.0100	255	290	320	65	17	40	0.90	0.7	0.1	0.2
	Flux	103.9				80				-					83.1	-	-			-	
	Converter Slag	250	4.8	47.	2.	26	2.2	5.7				12	120	5	65	9.5	8.1	.001	-	-	
lash Fce Output																					
	Matte	522	50.	23	23	-	2.5	2.09	0.042	0.009	.0017	261	120	120	-	13.0	10.9	0.22	0.05	0.009	0.0
	Slag	644	0.7	44.	1.5	33	1.09	4.58	.016	0.054	.0037	4.5	283.5	9.7	212.5	7.0	29.5	0.10	0.35	0.024	0.1
	To ESP Inlet	30	5	5	8	2	18	26	1.9			1.5	1.5	2.4	0.6	6.5	7.8	0.58	0.3	0.067	0.0
	Off-gas													192.9							
	Total											267	405.2	325	213.1	26.5	48.2	0.90	0.7	0.1	0.2
onv. Input																					
	Matte	522	50	23	23	-						261	120	120	-	13.0	10.9	0.22	0.05	0.009	.02
	Flux	81.2		0.6		80						-	0.5		65						
onv. Out																					
	Blister	252.3	98.5	0.1	0.1	-	0.59	0.1	0.035	0.02	-	248.5	-	-	-	1.5	0.25	0.089	0.03	-	-
	Slag	250	4.8	48	2	26	3.8	3.24	.0004	0.001	0.0015	12	120	5.	65	9.5	8.1	0.001	-	.0031	.01
g ESP		10	5	5	8	2	20	26				0.5	0.5	0.8	0.2	2.0	2.5	0.13	0.02	0.0063	.01
	Off-gas											-	114.2								
	Total															13.0	10.9	0.22			
SP Inlet Dust		40	5	5	8	2	21.3	26	1.8	0.8	.18	2.0	2.0	3.2	0.8	8.5	10.3	0.71	0.32	0.073	0.07
cid PT Input												0.04	0.04	0.06	0.016	0.26	0.309	0.60	0.128	0.072	0.06

FIG. 3·2·4 DIRTY COPPER CONCENTRATE CASE III
ELEMENT DISTRIBUTION IN A FLASH SMELTING CIRCUIT

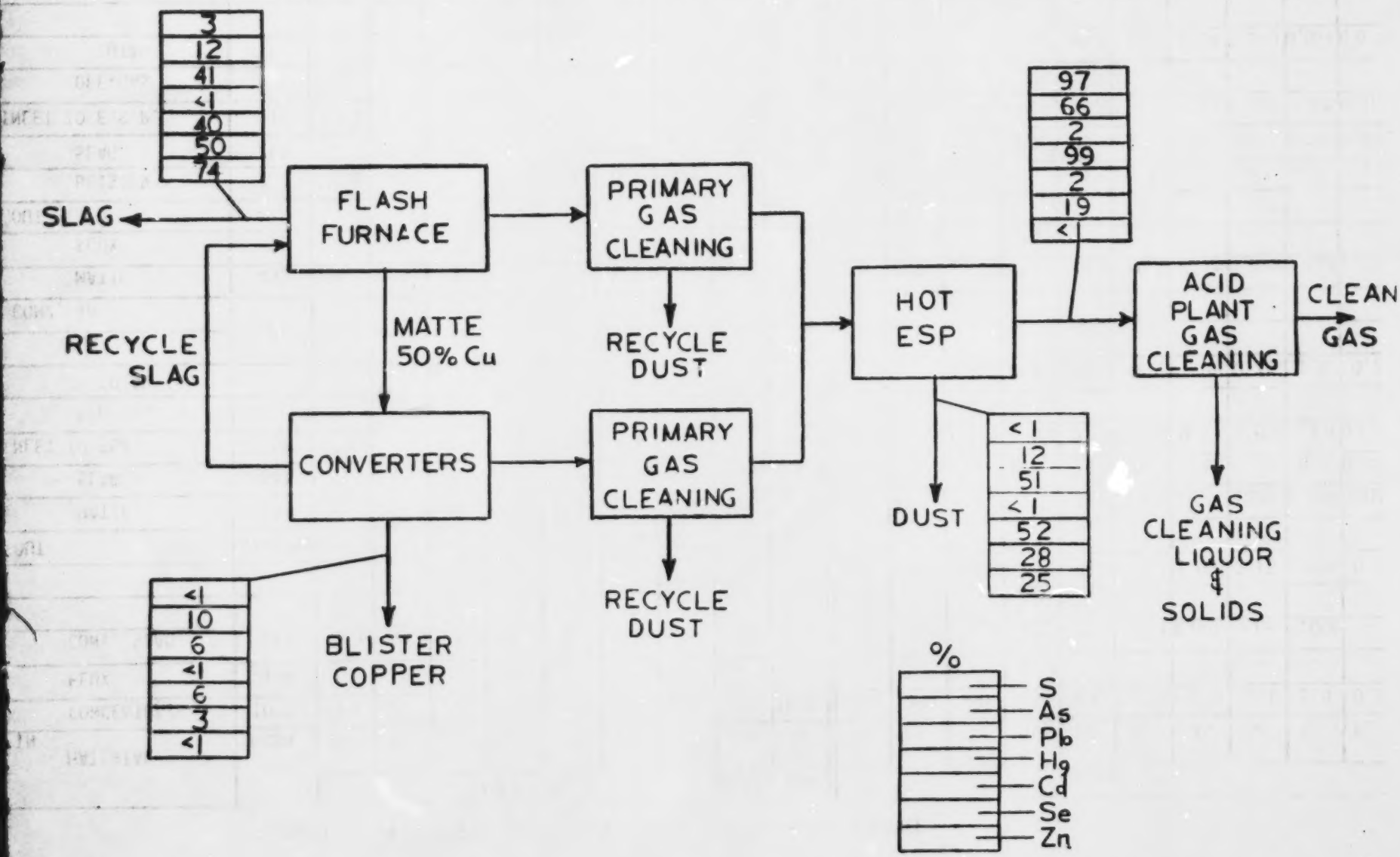


TABLE 3.2.4. DIRTY CONCENTRATE: CASE III MATERIALS BALANCE

MATERIAL		ASSAY WT. %							ASSAY ppm		mtpd.								
IN	mtpd	Cu	Fe	S	SiO_2	Pb	Zn	As	Cd	Se	Cu	Fe	S	SiO_2	Pb	Zn	As	Cd	Se	F.
CONCENTRATE	1000	24	28	30	6.5	6.	4.	0.1	100	1000	240.	280.	300.	65.	60.	40.	1.0	0.1	1.0	0.2
FLUX	108				80			-	-		-		-	86.4	-	-	-	-	-	-
CONV. SLAG	259	4.6	43.7	1.9	24.2	12.7	2.82	0.001	0.011		12.	113.	4.8	62.7	33.	8.1	0.001	0.05	.006	-
											252	393	304.8		93.	48.1	1.001	0.15	1.006	0.2
OUT	Slag/Matte					(0 41)	(2.5)	(0.4)	(0.4)	6										
MATTE	492	50	23	23	-	9.25	1.97	0.048	.0085	0.013	246	113.2	113.2	-	45.5	10.9	0.24	.073	0.064	0.018
SLAG	647	0.7	43	1.5	33	3.8	4.95	0.019	.0036	0.077	4.5	278.3	9 7	213.5	24.6	29.5	0.12	0.04	0.5	0.048
INLET TO ESP	52					47.7	15.6	1.28			1.5	1.5	2.4	0.6	22.9	7.8	0.64	0.038	.436	0.134
OFF-GAS													179.5							
TOTAL													304.8	214.1	93.	48.2	1.0	0.15	1.0	0.2
CONV. IN																				
MATTE	492	50	23	23	-	9.25	1.97	0.048	0.0085	0.013	246	113.2	113.2	-	45.5	10.9	0.24	0.073	0.064	0.018
FLUX	79	-	-	-	80	-	-	-	-	-	-	0.5	-	63	-	-	-	-	-	-
OUT																				
BLISTER	237.1	98.5	0.1	0.1	-	1.48	0.1	0.041	0.002		233.5	-	-	-	3.5	0.25	0.097	0.006	0.03	-
SLAG	259	4.6	43.7	1.9	24.2	12.7	2.82	0.001	0.011		12	113.2	4.8	62.7	33.	8.1	0.003	0.05	.006	0.00
INLET TO E.S.P.	19	2.6	2.6	42	1.1	47.3	11.6	0.74	0.044	0.14	0.5	0.5	0.8	0.2	9.0	2.5	0.14	0.017	0.026	0.01
OFF-GAS											-		107.6							
TOTAL															45.5	10.9	0.24	0.073	0.064	0.01
ESP INLET	71.					44.9					2.0	2.0	3.2	0.8	31.9	10.3	0.78	0.055	0.462	0.14
											0.04	0.04	0.06	0.016	0.96	0.309	0.66	.0019	0.185	0.144

3.2.5 Summary of Impurities in the Gases following Coarse Dust Removal and Acid Plant Design Requirements

Approximate maximum permissible dust loadings in gases flowing to the scrubbing section of the acid plants have been established to ensure reliable gas cleaning results using conventional low cost systems. These guidelines are shown in Table 3.2.5-A. The data shows acceptable concentrations of impurity elements in Case I. However, for Cases II and III, many of the contaminating elents are close to the limit, especially mercury and fluoride in Case III.

For comparison, design limits for cleaned gas entering the acid production section of the plant are shown in Table 3.2.5-B. The proportion of these elements which are removed during scrubbing ranges from a reduction by a factor of less than 10 to more than 800. Selenium and mercury fume reductions are the least while dust removal is very high.

3.3 Material Balances Outlining Scrubber System Performance Characteristics

3.3.1 General Gas Cleaning Requirements

Production of sulphuric acid requires effective gas cleaning to achieve the following:

i) Minimize dust build-up in the catalyst bed to minimize the bed pressure drop and the bed cleaning requirements.

ii) Minimize catalyst fouling.

iii) Minimize contamination of the product acid.

iv) Minimize corrosion.

TABLE 3.2.5-A

GAS IMPURITY CONCENTRATIONS
AFTER COARSE DUST REMOVAL - DESIGN & CASE EXAMPLES

Substance	Impurity Concentrations - Dry Gas Basis mg/Nm^3			
	Approximate Design Limit	Case I	Case II	Case III
Chlorides, as Cl	125	20	20	20
Flourides, as F	25	18	23	46
Arsenic, as As_2O_3	200	3.5	249	274
Lead, as Pb	200	6.3	82.1	303
Mercury, as Hg	2.5	0.015	0.31	31.2
Selenium, as Se	100	5.9	40.1	58
Total Solids (Dust)	1,000	200	200	200
Water	400×10^3	Limit	Limit	Limit

TABLE 3.2.5-B

UPPER IMPURITY LIMITS FOR CLEANED SMELTER GAS AFTER CLEANING & CONDITIONING

Impurity	Trace Element Concentrations - Dry Basis mg/Nm^3
	Approximate Design Limit
Chlorides, as Cl	1.2
Flourides, as F	0.25
Arsenic, as As_2O_3	1.2
Lead, as Pb	1.2
Mercury, as Hg	0.25
Selenium, as Se	50
Total Solids (Dust)	1.2
H_2SO_4 Mist, as 100% H_2SO_4	50

Gases from metallurgical operations typically report to the acid plant scrubber at 250 to 400°C. This temperature maintains the gas above the dewpoint until the gas is quench by scrubber sprays. Incoming gas dust loadings can be in the order of 1,000 illustrating the very effective nature of the cleaning function. An even more stringent cleaning is achieved for SO_2 liquefication.

3.3.2 Case I - Clean Concentrate Scrubbing Circuit and Materials Balance

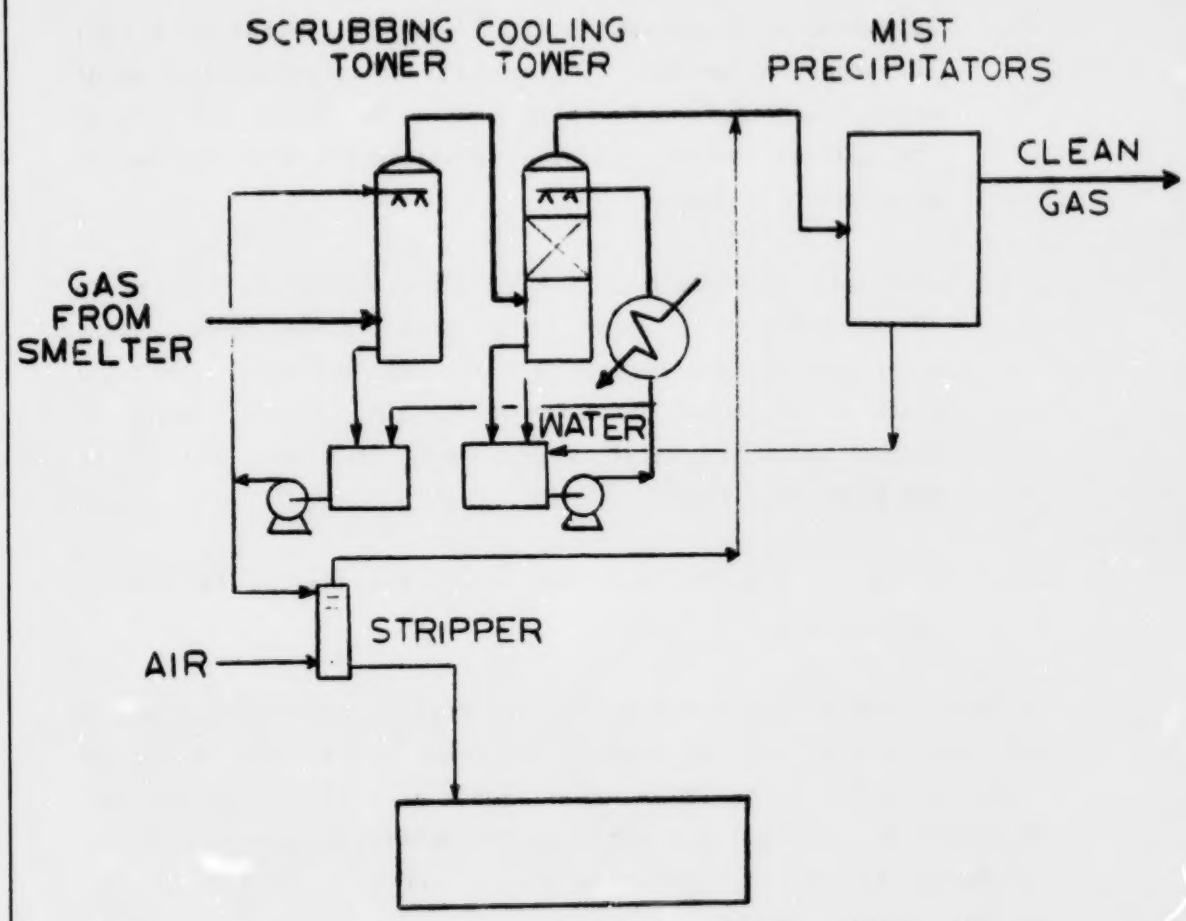
The gas cleaning and effluent treatment circuits processing gases and scrubber slurry produced during smelting of "clean" concentrate are shown in Figure 3.3.2 as a block diagram.

Incoming gases are scrubbed in a humidifying chamber with recirculating liquor. Partially cleaned, and partially cooled dusty gas proceeds to a second cooler section which removes additional particulate and fume and establishes the temperature of the gas entering the acid production area. Gas cooling is carried out using one of the following configurations:

- a tray tower atop the humidifier;
- a packed tower following the open humidifying tower;
- a shell and tube exchanger which cools indirectly thus reducing the effluent treatment requirement.

Following the gas cooler, a mist precipitator section provides the final gas cleaning function.

All liquor produc in the gas cleaning section is typically collected in a common vessel. This practice makes identification of the collection efficiencies of the three stages difficult; sampling of the various product streams is not common.



CASE I GAS CLEANING AND EFFLUENT TREATMENT
BLOCK DIAGRAM

NO.	REVISION	BY	DATE

PROJECT TITLE

	CONST.	DWG.
MADE		
CH'D.		
APP.		
DATE		

Fenco
FENCO ENGINEERS INC.

SCALE NTS

DWG. FIG 33.2 REV. 0

Certain design rules limit the concentration of various components in the recirculating liquor and establishes the recirculation liquor bleed rate. They are the following:

i) Sulphuric acid content in the liquor is limited to 5 to 1 10 percent by weight. This permits efficient collection of acidic chloride and fluoride fume. The vapour pressure of the halogen species increases dramatically with increasing acid concentration.

ii) Fluoride ion content of the scrubbing liquor is limited to 50 to 100 ppm. Above this concentration range common materials of construction are subject to stress corrosion cracking and other corrosion mechanisms. Tower linings of carbon block and metallic components of a high alloy like 904 L are required.

iii) Solids in the recirculating liquor are limited to 1 to 2 percent to avoid plugging.

In Case I the fluoride content is the primary limitation. Solids and acid content are secondary. In order to maintain 75 ppm of fluoride in the recirculation tower liquor a bleed rate of 530 lpm. is required. Table 3.3.2 outlines the materials balance for the scrubbing system including the collection efficiencies of the various cleaning system.

3.3.3 Case II - Moderately Dirty Concentrate Scrubbing Circuit and Materials Balance

With increasing levels of impurity elements in concentrates, the solids collected in the scrubber increases. Since, in this study, the silicate, oxide, and sulphate rates remain constant for a given concentrate feed rate (in all cases), increased scrubber circuit solids are due to higher impurity element rates to the E.S.P.

Table 3.3.2: Clean Concentrate: Case I - Acid Plant Materials Balance

MATERIAL	Solids Kg/d	ASSAY WT. %									kg/d								
		Pb	Zn	As	Hg	Se		Cl	F	Other Dust	Pb	Zn	As	Hg	Se		Cl	F	Other Dust
"Clean Conc." Scr.Feed	430	4.0	5.4	1.7	0.01	3.8	---	12.7	11.7	44.9	20	27	8.4	0.049	18.8	---	63	58	223
Scrubber-ESP U/F	425	4.7	6.3	2.0	0.008	4.32	---	14.6	13.2	52.3	19.9	26.96	8.36	.032	18.4		61.9	57.0	222.3
Catalyst Fouling	4.0										0.08	0.11	0.03	.009	0.32		0.99	0.8	0.6
		← ppm →																	
Acid Fouling	0.75	<0.1	<0.1	<0.1	<0.1	<0.1	---	0.1	0.1	<0.1	0.015	0.02	0.007	.006	0.06		0.17	0.15	0.05
Stack Exhaust	0.25*										0.005	0.01	.003	.002	0.02		0.06	0.05	0.05
TOTAL											20.	27.	8.4	0.049	18.8		63	58	223
		mg/Nm^3																	
Scrubber Feed Gas		6.31	8.51	3.49** (2.65 As)	0.015	5.93	---	19.8	18.2	200									
Scr. Syst. Outlet Gas		0.03	0.042	0.018 (.012 As)	0.005	0.12	---	0.34	0.3	1.									

* estimate only

** As_2O_3

Appendix C shows the E.S.P. efficiencies used to predict the scrubber feed composition. The scrubbing and effluent treatment circuits are outlined in Figure 3.3.3. The effluent treatment method is described in detail in Section 5.

As in Case I the fluoride concentration sets the scrubber liquor bleed rate. The Case II scrubber circuit uses standard materials of construction applicable for low fluoride liquors. Table 3.3.3 outlines the materials balance for the scrubbing system circuit.

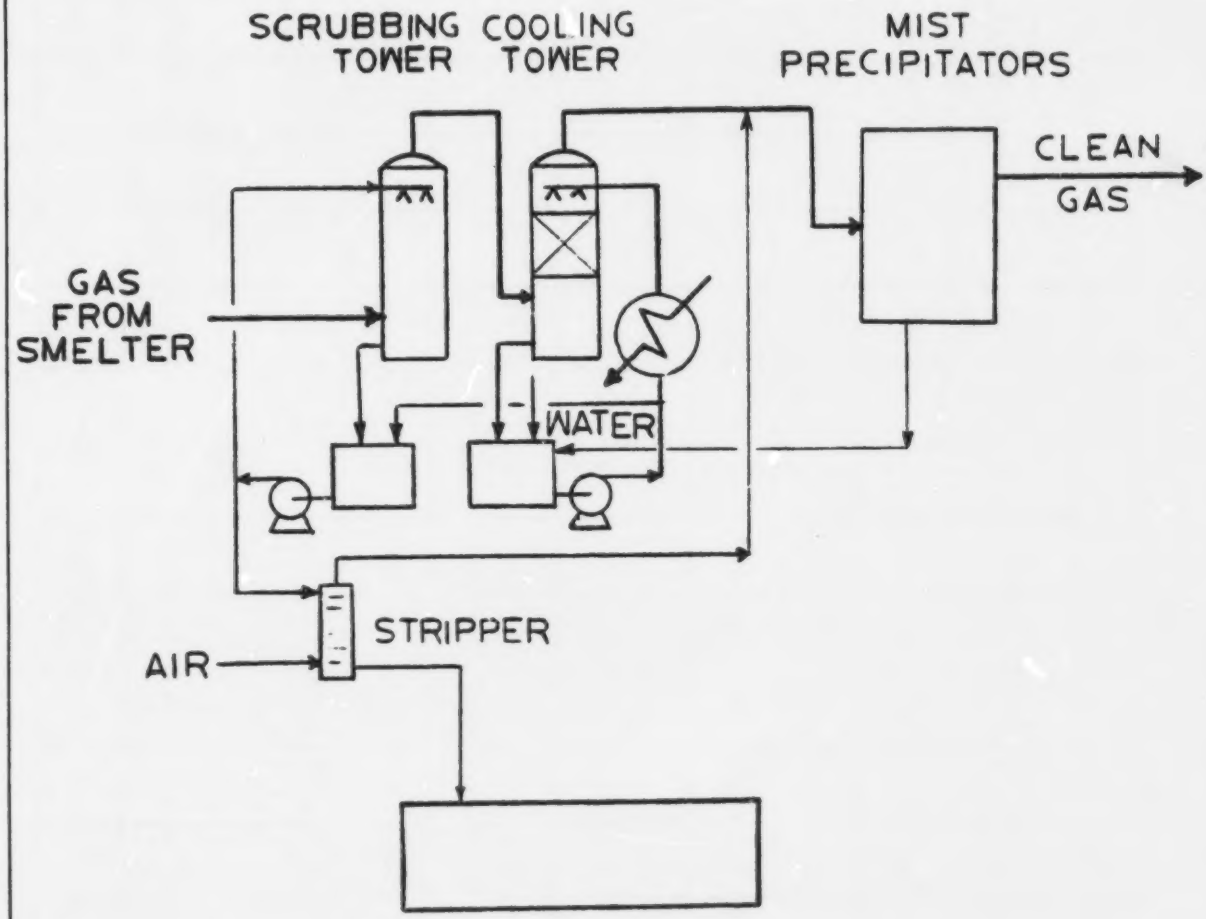
3.3.4 Case III - Dirty Concentrate Scrubbing Circuit and Materials Balance

The high level of impurity elements found in Case III concentrate requires sophisticated gas cleaning equipment. High fluorides necessitate the use of a carbon block lining in the humidifier tower and an FRP packed cooling tower. Metallic components which are resistant to stress corrosion cracking must also be used.

A mercury level of 100 ppm in the concentrate could produce acid containing mercury approaching 100 ppm. To eliminate this, a further scrubbing unit is added following the mist precipitator. The mercury removal is similar to that practiced by Canadian Electrolytic Zinc in Valleyfield, Quebec. Mercury removal using chloride is extremely efficient, typically 99 percent, and reduces mercury in acid to 1 ppm or less.

The scrubbing and effluent treatment circuits are outlined in Figure 3.3.4. Details of the effluent treatment method are described in Section 5. The additional costs to treat the high fluoride and mercury levels in scrubber feed gas are discussed in Section 6.

Table 3.3.4 outlines the materials balance for the scrubbing system circuit.



CASE II GAS CLEANING AND EFFLUENT TREATMENT
BLOCK DIAGRAM

NO.	REVISION	BY	DATE

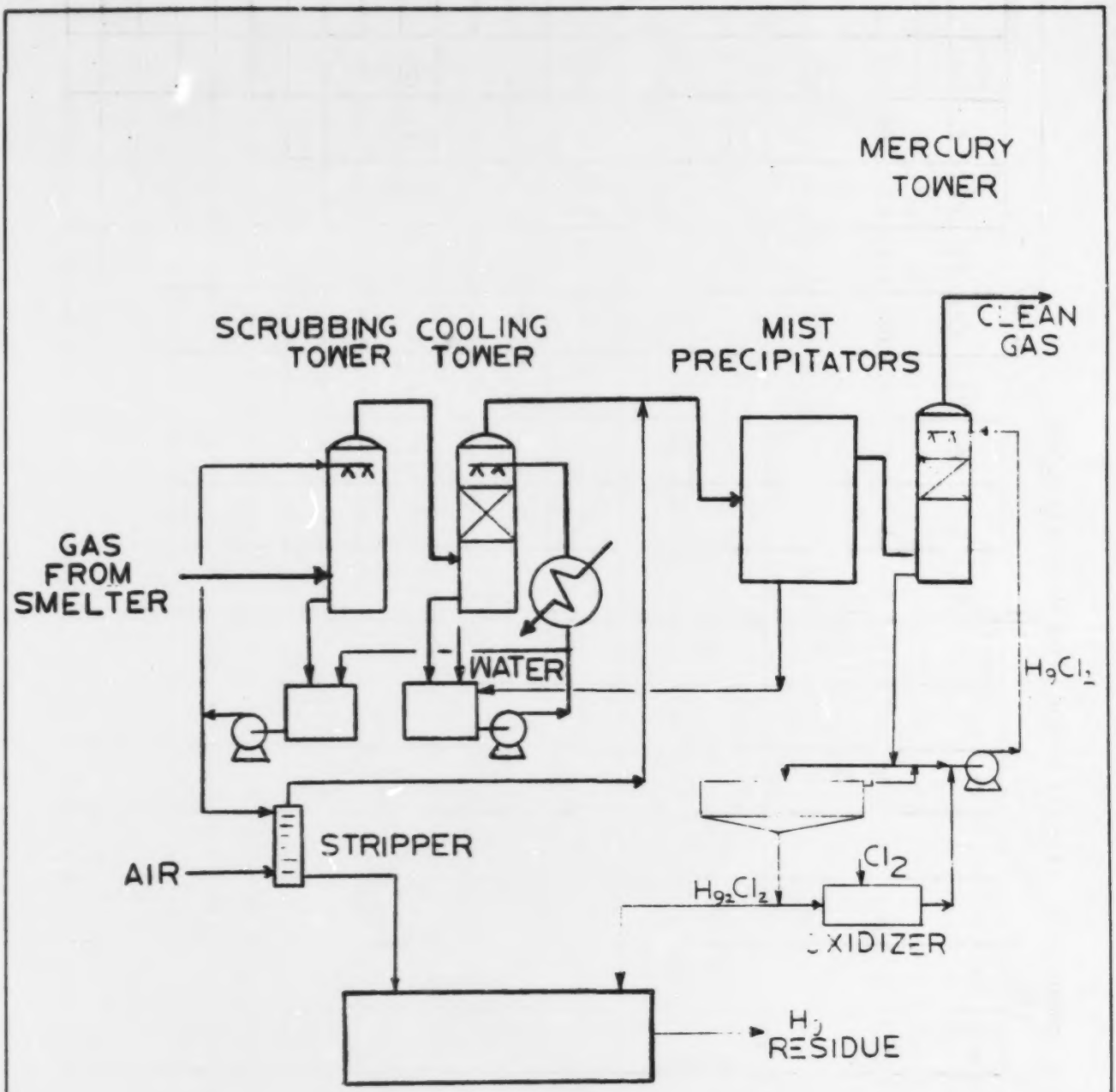
PROJECT TITLE

	COMP.	DWG.
MADE		
CH'D.		
APP.		
DATE		
DWG. FIG 3-3-3		

Fenco
FENCO ENGINEERS INC.
SCALE NTS
REV. 0

TABLE 3.3.3 MODERATELY DIRTY CONCENTRATE: CASE II ACID PLANT MATERIALS BALANCE

MATERIAL	dry kg/day	ASSAY WT. %									kg/day								
		Pb	Zn	As	Hg	Se		Cl	F	other dust	Pb	Zn	As	Hg	Se	Cd	Cl	F	other dust
Scrubber Feed	1959	13.3	15.8	30.6	0.05	0.07		3.2	3.7	11.4	260	309	600	0.99	128	-	63	72	223
											70/99	70/99	50/99	30/50	50/95	-	40/97	40/97	70/99
Scrub & Mist Ppt Catch	1935										259	307.5	597	0.64	125.4		61.9	70.8	222.3
Catalyst Fouling	19.2										0.8	1.2	2.4	0.17	2.05	-	0.91	0.96	0.6
		← Acid ppm →																	
Acid Fouling	3.6	0.1	<0.1	0.4	0.1	0.4	-	0.1	0.1	<0.1	0.15	0.23	0.45	0.13	0.38		0.17	0.18	0.05
Acid = 920 mtpd																			
Stack Exhaust	1.2										0.05	0.08	0.15	0.05	0.13		0.06	0.06	0.05
TOTAL	1959										260	309	600	0.99	128	-	63	72	223
		mg/Nm^3																	
Feed Gas	-	82.1	98	249 As_2O_3	0.31	40.1		20	23	70									
Scr. Sys. Outlet Gas		0.32	0.49	1.25 As_2O_3	0.096	0.85		34	0.36	0.22									



CASE III GAS CLEANING AND EFFLUENT TREATMENT
BLOCK DIAGRAM

NO.	REVISION	BY	DATE	PROJECT TITLE

	COMP.	DWG.
MADE		
CH'D.		
APP.		
DATE		
DWG. FIG 3.3-4		

Fenco
FENCO ENGINEERS INC.
SCALE NTS
REV. 0

Table 3.3.4: Dirty Concentrate: Case III - Acid Plant Materials Balance

MATERIAL	dry Kg/day	ASSAY WT. %									kg/day								
		Pb	Zn	As	Hg	Se	Cd	Cl	F	other dust	Pb	Zn	As	Hg	Se	Cd	Cl	F	other dust
SCRUBBER FEED	2944	32.6	10.2	22.4	3.4	6.3	0.05	2.1	4.9	7.6	960	300	660	99	185	1.4	63	144	223
% Scrub % mistppt.																			
SCRUB&MIST Ppt Catch	2888	33.1	10.3	22.7	2.2	6.2	0.05	2.1	4.9	7.7	957	298.5	656.7	64.4	180.	1.39	61.9	141.5	222.
CATALYST FOULING	8.9										1.2	0.6	1.32	0.4	1.84	0.04	0.45	1.0	0.3
		◄			ACID	ppm				►									
ACID FOULING	3.31	0.5	0.2	0.5	0.39	0.8	<0.1	0.1	0.4	.05	0.45	0.23	0.49	0.3	0.69	0.02	0.17	0.31	0.05
Acid 862 mtpd																			
Stack Exhaust	1.11										0.15	0.08	0.17	0.1	0.23	--	0.06	0.13	0.05
Hg Scrubber	43				78.8						1.2	0.6	1.32	33.9	1.84	0.04	0.45	1.0	0.3
Total	2944										960	300	660	99.	185	1.4	63.	144	223
					mg / Nm^3														
Scrubber Feed Gas	-	303	95	208	31.2	58	0.004	20	46	70.									
				274 As_2O_3															
Scrubber System Outlet Gas	-	0.95	0.48	1.05	0.22	1.5	0.03	0.34	0.74	0.22									
				1.38 As_2O_3															

3.3.5 Summary of Clean Smelter Gas Impurity Concentrations

Typical design dust load reductions in the gas cleaning secton ol acid plants were discussed in Section 3.2.5. The residual concentrations of trace elements in the cleaned gas entering the acid production section of the plant are shown in Table 3.3.5 for the three cases investigated. Concentrations predicted are within acceptable limits or within expected error of measurement possible for dust sampling and analysis.

TABLE 3.3.5 - UPPER IMPURITY LIMITS FOR CLEANED SMELTER GAS AFTER GAS CLEANING AND CONDITIONING

Impurity	Trace Element Concentrations - Dry Basis mg/Nm^3			
	Approx. Design Limit	Case I	Case II	Case III
Chlorides, as Cl fume	1.2	0.34	0.34	0.34
Fluorides, as F fume	0.25	0.30	0.36	0.74
Arsenic, as As_2O_3 fume	1.2	0.018	1.25	1.38
Lead as Pb fume	1.2	0.03	0.32	0.95
Mercury, as Hg gas	0.25	0.005	0.096	0.22
Selenium, as Se gas	50	0.12	0.85	1.5
Total Dust	1.2	1.	1.	1.
H_2SO_4 Mist, as 100% H_2SO_4	50			

SECTION 4

SCRUBBERS IN CANADA

4.0 SCRUBBERS IN CANADA

4.1 Summary of Canadian Acid Plant Scrubber Operations

Metallurgical gases suitable for sulphuric acid are currently produced by a wide variety of roasting and smelting operations. Table 4.2.1 outlines the operations and the gas cleaning methods employed.

Dust which is not collected in the gas cleaning section of the plant fouls the calalyst bed. This necessitates costly annual cleaning. More modern plant design involves the installation of two first pass beds in parallel to extend times between cleanings and reduce the pressure drop produced by dust fouling.

4.2 Scrubbing and Humidification

The design approach adopted by most acid plant operators relies on a spray chamber to knock out most of the coarser inlet dust particles and some of the fume. Venturi sections on spray or humidification chamber inlets are installed in some of the more recent plants.

Venturi operations depend on high pressure drops to achieve efficient removal of very fine particulate materials. Cost effective elimination of fine, nuisance dust and fume determines the advantage of adding a venturi section. It appears most Canadian operators have managed without.

Gases from Inco's copper flash furnace are treated in a bank of three venturi ejector scrubbers, and a mist precipitator prior to SO_2 liquifaction.

Brunswick Smelting utilizes a bank of four venturi type scrubbers operating at a low pressure drop.

TABLE 4.2.1

SUMMARY OF CANADIAN METALLURGICAL GAS CLEANING OPERATIONS PRECEEDING SULPHURIC ACID PRODUCTION

Operations	SO_2 Source	Gas Cleaning Circuit Configuration			Scrubber Effluent Treatment
		Scrubber	Cooler	Mist Precipitators	
Falconbridge Ltd. (11) (Sudbury)	Fluid Bed Roaster (Ni/Cu)	Spray Chamber	Integrated Tray Tower	2 Trains of 3 Ppt. in Parallel	Lime Neutralization/Tailings
Inco Ltd. No. 3 (7) (Sudbury)	Fluid Bed Roaster (Ni/Cu & Fe)	Spray Chamber	Integrated Tray Tower	3 Ppt. in Parallel	Data N/A
Kidd Creek (41) (Timmins)	Mitsubishi Cont. Copper Smelter	Venturi Inlet/ Spray Chamber	Integrated Tray Tower	2 Ppt. in Series	Neutralization/Filtering
Kidd Creek (24) (Timmins)	Fluid Bed Roaster (Zn)	Spray Chamber	Integrated Tray Tower	2 Ppt. in Series	Neutralization/Slurry to Tailings
C.E.Z. (10) (Valleyfield)	Fluid Bed Roaster (Zn)	Spray Chamber	Packed Tower	2 Ppt. in Series	Limestone Neutralization/ Slurry to Tailings
Gaspe Copper (49) (Murdochville, Que.)	Copper Converter	Spray Chamber	Integrated Tray Tower	3 Trains of 2 Ppt. in Parallel	Neutralization Circuit/ Tailings Disposal
Brunswick M & S (19) (Belledune, N.B.)	Lead Sintering Machine	Venturi Scrubbers (4 in parllel)	Packed Towers (1 + spare)	12 Ppt. in Parallel	Sinter Plant Water Reprocessing Circuit
Cominco (39) (Trail, B.C.)	Zinc Roasters	Glover Tower	Separate Tower	3 Ppt. in Parallel	Lime Neutralization/ Liquor to Columbia River
Cominco (39) (Trail, B.C.)	Lead Sintering Machine	Spray Chamber	-	Ammonia SO_2 Scrubber*	Treatment Unknown/Discharge to Columbia River
Inco Ltd. (21) (Sudbury) (SO_2 Liquification)	Copper Flash Furnace	Spray Chamber/ 3 Venturi Ejectors	-	Single ppt.	Lime Neutralization/ Tailings

*SO_2 regenerated for sulphuric acid production

4.3 Gas Cooling

Additional dust and fume are removed in the scrubbing gas cooling stage. Some operations have a tray tower atop the spray chamber. Another established configuration employs a packed tower in series with the spray chamber. The integrated tray tower is simplier and requires less maintenance and can thus be stacked. Packed towers are more maintenance intensive and are usually built at ground level. Brunswick Mining and Smelting operates with two packed towers which permits off-line cleaning of one unit without curtailing operation of the acid plant.

4.4 Mist Precipitator

Fine dust, fume, and acid mist passing the scrubbing steps are eliminated efficiently in electrostaiic mist precipitators. Recovery efficiencies of over 98 percent are necessary to achieve the clean gas specification outlined in Table 3.3.5. As noted in Table 4.2.1. mist precipitators are arranged in various configurations but are universally required.

4.5 Treatment of Gases Containing Large Quantities of Fume or Gases

High concentrations of fluorides and chlorides in scrubber liquor can preclude the use of metallic tray towers. Halides can induce stress corrosion cracking in stainless steels which have good general corrosion resistance. One solution is to line the humidifying tower with a non-metallic such as carbon brick. The cooling tower can be fabricated from reinforced plastic and packed with a non-metallic distributing medium.

Treating flue gases containing large quantities of an impurity such as mercury may require an additional scrubbing step. This is not a common requirement but has been necessary in at least one Canadian acid plant.

4.6 Scrubber Effluent Collection and Treatment

Liquor collected in the scrubber sump includes the captured scrubber/cooler and mist precipitator solids, and soluable species. A scrubber liquor bleed maintains an acceptable recirculating pH, halides concentration, and slurry density. The bleed stream is typically processed in a neutralization circuit consisting of stirred reactors or pachuca tanks fed with lime, limestone or a combination of the two alkalines. Lime is required to produce a final pH above 6 to 7. Following neutralization, the product slurry is typically discharged with mill tailings to a compound area. Special treatments including filtering to recover metal values have been incorporated into some plant designs..

Table 4.6.1 summarizes the data available on scrubber effluent production a treatment methods including the final disposal means.

TABLE 4.6.1

CANADIAN METALLURGICAL OPERATIONS: SUMMARY OF EFFLUENTS PRODUCED DURING GAS CLEANING AND THEIR DISPOSAL

Operations	Effluent mg/kg							Treatment	Disposal
	l/min	Pb	Zn	As	Hg	Cd	Se		
Falconbridge Ltd. (11) (Sudbury)	680	-	-	-	-	-	-	Lime Neutralization Tailings Dilution	Tailings Pond
Inco Ltd. Flash Furnace (Sudbury) *(24)	N/A	0.42	0.8	0.19	0.002	0.01	5.7	Lime Neutralization	Concentrator Tailings
Kidd Creek ** (Timmins)	N/A							Lime Neutralization	Holding Pond
Kidd Creek ** (Timmins)	N/A							Lime Neutralization	Holding Pond
C.E.Z. (24) (Valleyfield)	N/A	30.6	4600	81	145	15	27.5	Lime Neutralization	Tailings Circuit
Gaspe Copper (24) (Murdochville, Que.)	N/A	12.5	37.0	53	0.3	4.5	2.6	Tailings Disposal Circuit	Concentrator Tailings
Brunswick M & S (24) (Belledune, N.B.)	N/A	330	69	730	6.6	1772	3.6		Sinter Pt. Water Circuit
Cominco (24) (Trail, B.C.)	N/A	1.4	115	0.6	0.53	0.75	-	Lime Neutralization	Effluent to Columbia River

*dissolved species only
**telcom data

SECTION 5

SCRUBBER EFFLUENT TREATMENT

5.0 SCRUBBER EFFLUENT TREATMENT

5.1 Introduction

The effluent from an acid gas purification section typically contains 1-10% sulphuric acid and various metal elements. Regulatory interest is mainly concerned with the removal of precipitated and suspended metal salts, in view of their potentially toxic nature (Table 5.1.1). The standard means of control for removing these pollutants is precipitation with lime additions from basic solution using pH for control. The precipitated hydroxides are then settled out in a contaminant area.

5.2 Process Selection

5.2.1 General

Selection of a process is based on the following factors:

i) The effluent water quality requirement - this is mainly dependent on the receiving water body in the case of direct discharge to the surrounding environment.

Recycling the effluent to the plant water circuit after solids removal or discharge to the plant tailings area are possible alternatives. In some cases further and more exotic treatment may be required.

ii) Sludge disposal - the form of disposal that is practical at a particular site is dependent upon geographical, political and environmental considerations. The following options should be evaluated for any site specific application:

TABLE 5.1.1

SELECTED GUIDELINES FOR WATER QUALITY PARAMETERS

Parameters			Drinking Water (Maximum Acceptable Concentrations)	Marine Aquatic Life Protection (Guidelines)	Freshwater Aquatic Life Protection (Guidelines)
Total suspended solids		mg/L	-	-	< 25
Total dissolved solids		mg/L	< 500	-	-
pH		units	>6.5 - <8.5	>6.5 - <8.5	>6.5 - < 0.9
Arsenic	As	mg/L	<0.05	<0.05	<0.05
Cadmium	Cd	mg/L	<0.005	< 0.005	<0.0002
Lead	Pb	mg/L	<0.05	<0.05	<0.03
Mercury	Hg	µg/L	<1.0	<0.10	<0.1
Selenium	Se	mg/L	<0.01	<0.01	-
Zinc	Zn	mg/L	<5.0	<0.1	<0.03
Chloride	Cl	mg/L	< 250	-	-
Fluoride	Fl	mg/L	<1.5	-	-

a) disposal in a secure landfill;
b) disposal in the tailings area;
c) production of gyprock board using gypsum;
d) disposal to mine backfill;
e) partial recovery of contained elements.

A summary table showing the feeds to the effluent treatment plants is shown in Table 5.2.1.

5.2.2 Process Alternatives

Three flowsheet schematics for the effluent treatment plants are presented in Figures 5.2.2-1, 5.2.2-2, 5.2.2-3. The main difference between Case I and II, and Case III is the production of gypsum in Case III which can influence the overall cost benefit of the treatment system due to:

i) reduction in the volume of sludge containing the majority of pollutants and require disposal in a secure landfill;

ii) the production of gypsum for sale to a gypsum board plant.

Selection of the optimum process will be based upon a cost analysis encompassing capital outlay and operating costs, including consumption of chemicals, power, salaries, maintenance and sludge disposal.

5.2.3 Case I - Clean Concentrate Effluent Treatment Facility

Scrubber effluent together with lime slurry flow into a series of three air agitated pachuca tanks. Control of pH at approximately 10 precipitates the metals and gypsum. The product slurry is pumped to an existing tailings area and diluted with mill tailings and water from the environment.

TABLE 5.2.1 SUMMARY OF FEEDS TO SCRUBBER EFFLUENT TREATMENT SYSTEMS

DATE: January 30, 1984

MATERIAL	kg/d	ASSAY WT. %									kg/day.									
		Pb	Zn	As	Hg	Se	Cd	Cl	F	other* dust	Pb	Zn	As	Hg	Se	Cd	Cl	F	other dust	
"CASE 1"																				
SOLIDS (DRY)	425	4.7	6.3	2.0	0.008	4.32	-	14.6	13.4	52.3	19.9	26.96	8.36	0.032	18.4	-	61.9	57.	222.3	
WATER	760,320																			
SLURRY EFFLUENT	760.745			10.9 ppm	0.04 ppm	24.1 ppm			75 ppm				8.36	0.032	18.4					
~140 USGPM																				
"CASE 2"																				
SOLIDS (DRY)	1935	13.4	15.9	30.8	0.03	6.5	-	3.2	3.7	11.5	259	307.5	597	0.64	125.4	-	61.9	70.8	222.3	
WATER	944,640																			
SLURRY	946,575			631 ppm	0.6 ppm				75 ppm				597	0.64				70.8		
~173 USGPM																				
"CASE 3"																				
SOLIDS (DRY)	2888	33.1	10.3	22.7	2.2	6.2	0.05	2.1	4.9	7.7	957	298.5	656.7	64.4	180.4	1.39	61.9	141.5	222.3	
WATER	327,300																			
60 USGPM SCRUBBER SLURRY	330,200	2900 ppm		1990 ppm	195 ppm	546 ppm		187 ppm	430 ppm		957		656.7	64.4	180.4			141.5		
H_g TOWER (SOLIDS)	43				78.8						1.2	0.6	1.32	33.9	1.84	0.04	0.45	1.0	0.3	SG 6.3
WATER	18.4																			
H_g TOWER SLURRY																				
PRODUCT	61.4				55.2						1.2	0.6		33.9						2.7

*other dust contains: Cu, Fe, S, SO_4, Gangue.

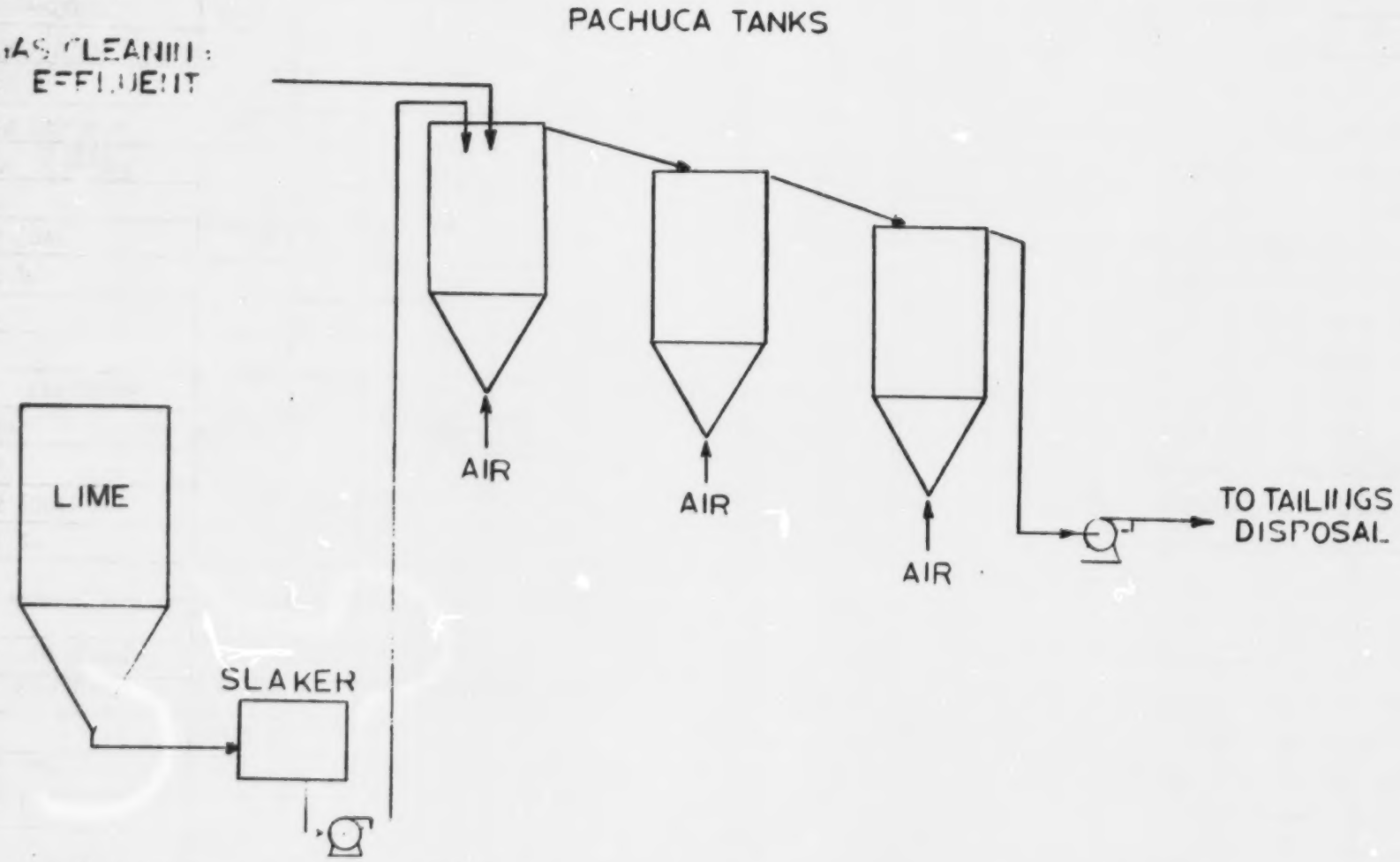


FIG. 5.2.2-1 CASE I - EFFLUENT TREATMENT FLOWSHEET

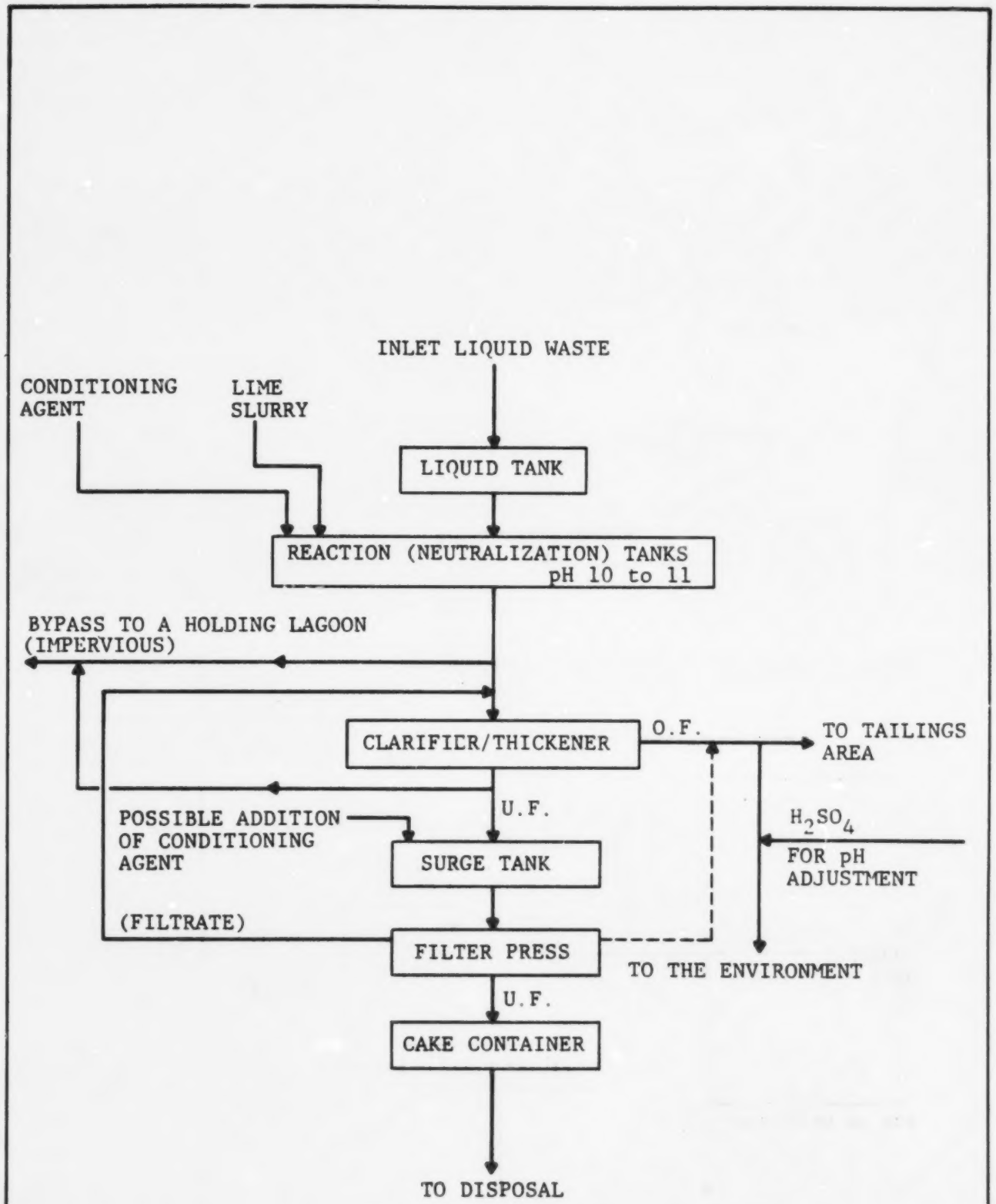


FIG. 5.2.2-2 EFFLUENT TREATMENT FLOWSHEET

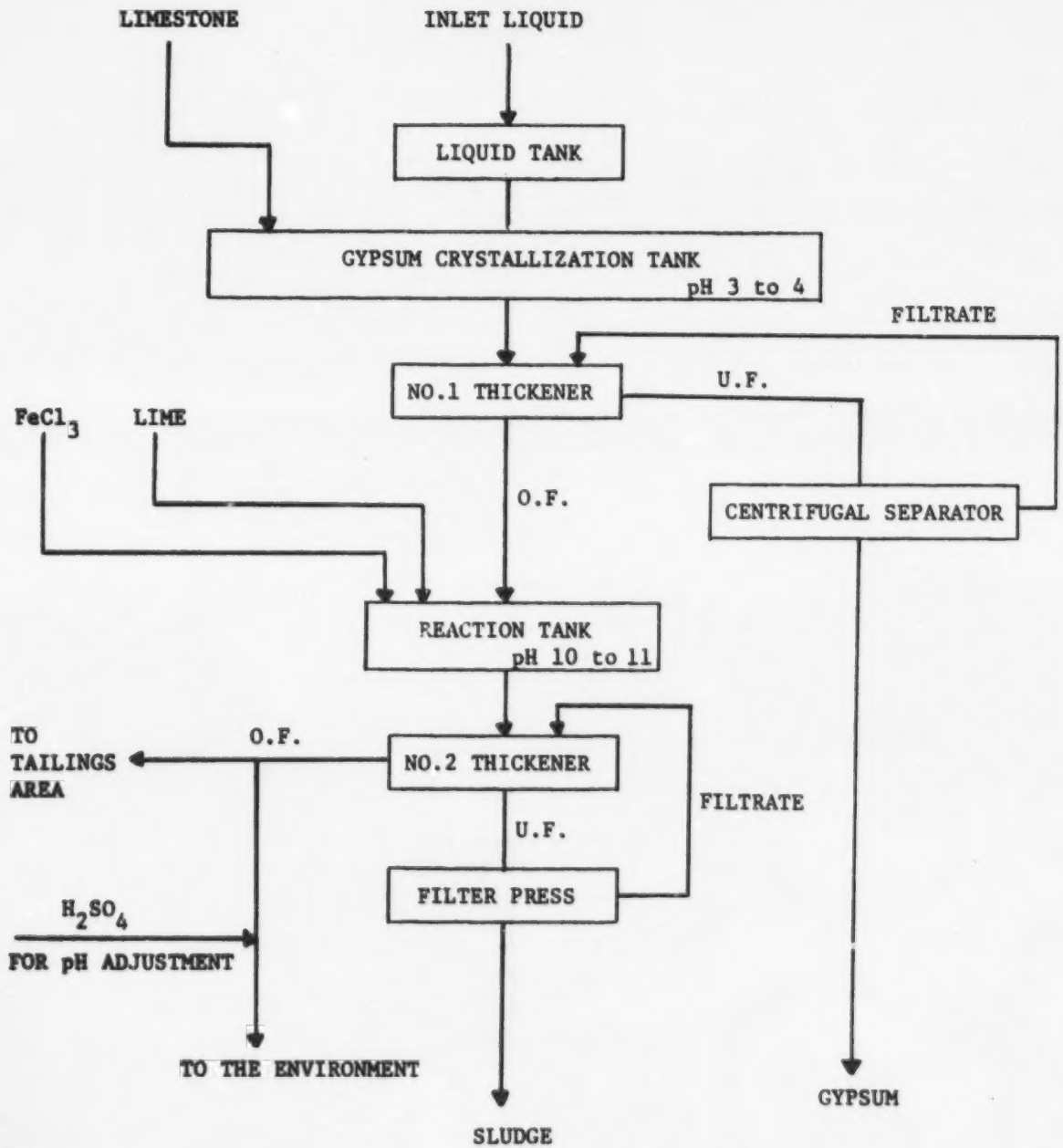


FIGURE 5.2.2-3: CASE III - EFFLUENT TREATMENT FLOWSHEET

5.2.4 Case II - Moderately Dirty Effluent Treatment Facility

The effluent is mixed with lime in a neutralization tank controlled at about 1 pH of 10, where most metal contents precipitate forming the sludge in the thickener. The overflow from the thickener is reused in the mill or discharged to the tailings area. The sludge produced could alternately be conditioned and dewatered for ultimate disposal as described in Section 5.3.6 and 5.3.7.

5.2.5 Case III - Dirty Concentrate Effluent Treatment Facility

In this alternative two stages of neutralization are proposed. The effluent is first mixed with calcium carbonate in the gypsum crystallization tank controlled in the pH range of 3-4, where the sulphate ion is separated as gypsum. The overflow from the No. 1 thickener could be neutralized further with lime in the second neutralization tank controlled at about a pH of 10, where most metal contents are removed. The sludge precipitated in the second neutralization tank is sent through the No. 2 thickener to be filter-pressed. The overflow from the No. 2 thickener could be discharged to the tailings area directly or neutralized with sulphuric acid to the pH of 7 and disposed. The tonnages of gypsum and sludge produced would vary depending on the fluctuation of the quality and quantity of the incoming flow.

It should be noted that several investigators reported that the addition of precipitated or ground rock gypsum as seed nuclei to low concentration sulphuric acid wastes prior to lime neutralization affected a dramatic increase in the sludge suspended solids concentration corresponding to a proportional reduction in sludge volume.

5.2.6 Major Difference Between Case II and Case III

The feeds to the scrubber effluent treatment system differ in quantity and quality for both Case II and Case III as presented in Table 5.2.1. However, the flowsheet for the treatment process for both cases will be similar.

The following points identify the major differences between the two cases:

i) Although the amount of acid in the waste stream for the two cases is similar (4.81 kg - H_2SO_4/min.), it is anticipated that lime consumption for Case II will be slightly higher than Case III due to the larger volume of waste requiring the pH to be raised. The difference in lime requirements is not anticipated to be significant. Due to the lack of titration curves to calculate the lime requirements for both cases, a historical data from similar installations has been used as a guide.

ii) Due to the high concentration of metals in Case III in comparison with Case II, it is recommended to crystallize gypsum before the lime addition. This would result in the concentratino of metals in a relatively small volume of sludge that require disposal in a secure landfill.

iii) The concentration of H_2SO_4 in the two streams is different, less than 1% for Case II and more than 2% for Case III. The density or solids content of the sludges tends to increase as the acid concentration is increased, resulting in progressively less volume of sludge per unit weight of acid neutralized. However, the volume of sludge in Case III is anticipated to be higher than Case II due to the higher concentration of solids.

iv) Case III is provided with a mercury recovery circuit which produces a waste stream (70% solids by weight) containing 40% mercury. Due to the small volume of this waste stream (50.3 lpd), and its intermittent discharge, it is recommended to be temporary stored in drums (about 115 drums/year) in a secure area in the plant for future ultimate disposal in a secure landfill or sale to a refinery.

5.3 Unit Process Description

5.3.1 Lime Supply

Considerable savings can be affected by using bulk lime. Delivery of bulk lime is handled by truck or rail. The amount of lime needed per day is about 15 tonnes depending on the quality of the waste stream. The cost to the plant gate is about $110/tonne.

5.3.2 Bulk Storage of Lime

Since lime is not corrosive, conventional steel or concrete bins and silos can be used for storage. The steel silo with a conical bottom is common. The storage units must be watertight and airtight. Lime is perishable, particularly quicklime which is subject to air slaking.

Storage: 40 tonnes unit - capacity: 43 m^3.

- 3.7 m diameter, 6.1 m high and 60° cone
- storage: 8 days supply of pebble quicklime

5.3.3 Lime Feed System and Slaker

A volumetric belt feeder is recommended. It is recommended a continuous paste slaker be used. The lime slaker provides sufficient contact time to complete hydration while continuously feeding the reactor tank.

5.3.4 Reaction (Neutralization) Tank

The feed from the lime slaker to the reaction tank is controlled according to the desired pH at the reaction tank.

The use of two or three reaction tanks in series is advantageous.

Adequate mixing during pH adjustment improves the utilization of lime and the settling characteristics of the sludge. For removal of arsenic, ferric Chloride is added for co-precipitation with Fe.

The pH in the reaction tank is selected to achieve the most complete separation of metals. It is anticipated that a pH level in the range of 10-11 will be the most efficient.

For the purpose of cost estimating half an hour detention time in each reactor is assumed.

5.3.5 Clarifier/Thickener

Particles settle from suspension in different ways, depending upon the concentration of the suspension and the characteristics of the particles.

Rate of settling of the precipitated hydroxides vary, precipitated, gel-like zinc hydroxide settles very slowly. However, co-precipitation with copper hydroxide and the presence of iron, as ferrous and ferric sulphate, help to flocculate the precipitates and aid in settling.

From consideration of solubility products of the reaction products, the quantity of insoluble material formed by neutralization of a given acid with a given alkali can be estimated. However, the volume of sludge formed rather than the weight is of principal interest because it represents the quantity of material to be handled. For waste acid solutions containing various precipitable impurities, the only reliable means of determination of the effect of alkaline agent upon sludge volume is by experimentation.

Inspite of the difference in waste volume between the two cases, the size of the thickener will be similar as the design criteria is governed mainly by the solids loading. For cost estimating purposes a loading of 100-150 kg/m^2/day has been assumed. This correspond to about a 12 m. diameter thickener.

5.3.6 Sludge Conditioning

If sludge is dewatered using a press filter, an open cake structure with high permeability is desired. It is also necessary that the structure have a high resistance to compression so that permeability is retained when a pressure differential is imposed on the sludge cake. Trial-and-error experimentation with a variety of conditions is needed. Sludges are most frequently conditioned by chemical means. Chemical treatment usually involves coagulation - flocculation of sludge solids with polymerized hydrolysis products of multivalent metal ions and/or natural or synthetic organic polymeric material to form an agglomerated, expanded structure.

Chemical conditioning is influenced by variable such as the age of the sludge, the dilution and age of the conditioning chemical, and the degree and time of mixing of the conditioned sludge prior to dewatering.

Conditioning of sludge could be provided in the sludge surge tank which is assumed to have three hour retention period. An alternative addition point could be the reaction (neutralization) tank.

5.3.7 Filter Press

All sludge handling and dewatering procedures are designed to prepare a product that will be suitable for practical disposal. The filter press will produce a cake sufficiently dry to be conveyed into dump trucks. The dewatering characteristics of sludges in a filter press depends on factors such as the concentration, size, shape, and surface characteristics of the sludge particles, the extent of aggregation, the structural characteristics of the particles, and the viscosity, ionic strength, and pH of the suspending water.

Knowledge of the influence of these and other variables on the case with which water can be removed from sludge has not progressed to the extent that filterability predictions can be based on direct measurements of basic properties. Instead, it is necessary to measure performance parameters which reflect the combined influence of the variables.

The recommended filter press was chosen based on the following criteria:

Type:	chamber filter press
Feed:	2 1/s sludge, 8% solids
Cake:	solids, 50% assumed for lime sludge
	density, 1200 kg/m
Cycle time:	3 cycles/8 hr. shift
Pressure:	689 kpa typical
Chamber volume required:	2.57 m^3

5.3.8 Emergency Bypass Lagoon

In the case of treatment plant upsets or uncounted for surges, it is recommended to provide an emergency bypass lagoon. The lagoon should be impervious to protect the groundwater regime. The bypasses in the system could be provided at the following locations:

a) the inflow to the treatment system;

b) at the outflow from the neutralization (reaction) tank;

c) at the inflow to the sludge surge tank prior to the filter press.

The sizing of the lagoon is dependent on the economics of its size versus the potential risk.

SECTION 6

COSTS - CAPITAL AND OPERATING

6.0 COSTS - CAPITAL AND OPERATING

6.1 Basis of Capital Costs

Capital costs were developed for three sulphuric acid production facilities, namely 600, 1000 and 1500 mtpd plants, for smelting operations processing the three concentrates described in Section 3. Cost data were based on our recent installations. Corrections were made for inflation and plant capacity as required.

The basic costs do not include the following:

i) land costs;
ii) interest on capital during construction;
iii) owner's engineering expenses;
iv) working capital;
v) environmental approvals;
vi) allowance for interruptions of on-going operations;
vii) new tailings storage compound;
viii) new tailings lines.

Items i) to vi) typically amount to approximately 20% of the total costs in the following tables.

Items v) was not included due to its site specific nature. As well, Items vii) and viii) are very site specific and beyond the scope of this study.

The accuracy of the cost estimate are +50, -10%.

6.2 Capital Costs for Case I Clean Concentrate

Processing gases and effluents produced during smelting of clean concentrate (Case I) is relatively straightforward compared to the dirtier concentrates. Extra cleaning unit operations or more complicated construction techniques required for example when halide circulating loads rise, increase capital costs appreciably.

Table 6.2.1 outlines the costs of the gas cleaning and effluent treatment estimated for Case I for three levels of sulphuric acid production.

6.3 Capital Costs for Case II - Moderately Dirty Concentrates

Case II costs increase over those for Case I due to increased sludge solids handled, and separation of a sludge product in the effluent treatment facility as outlined in Figures 3.2.2 and 5.2.2.

Table 6.3.1 shows capital costs for gas cleaning and effluent treatment plant areas for three levels of sulphuric acid production.

6.4 Capital Costs for Case III - Dirty Concentrate

Costs for gas cleaning and effluent treatment for Case III increase significantly over Cases II due to higher fluorides in the recirculating scrubber liquor and the need for an additional mercury removal tower. The scrubbing system is discussed in Section 3.

Effluent treatment plant costs are slightly higher due to the increased solids handling requirement and off-set by the reduced liquid flows. The effluent treatment plant is outlined in Section 5.

TABLE 6.2.1

SUMMARY OF CAPITAL COSTS FOR SCRUBBING AND EFFLUENT TREATMENT FOR CASE I - CLEAN CONCENTRATE

Cost Area	$		
	600 mtpd	1000 mtpd	1500 mtpd
1. Gas Cleaning Area (including scrubbing, gas cooling, mist precipitators and ancillaries shown in Figure 3.3.1)	2,994,000	4,061,700	5,103,000
2. Effluent Neutralization (described in Figure 5.2.1)	562,300	692,300	886,100
TOTAL	3,556,300	4,754,100	5,989,100

TABLE 6.3.1

SUMMARY OF CAPITAL COSTS FOR GAS CLEANING AND EFFLUENT TREATMENT PLANT AREAS FOR CASE II - MODERATELY DIRTY CONCENTRATE

Cost Area	$		
	600 mtpd	1000 mtpd	1500 mtpd
Gas Cleaning Area (described in Figure 3.2.2)	3,297,500	4,452,400	5,695,300
Effluent Treatment (described in Figure 5.2.2)	1,472,800	2,030,000	2,547,500
TOTAL	4,770,300	6,482,400	8,242,800

Table 6.4.1 summarizes capital costs for gas cleaning and effluent treatment plant areas for three sulphuric acid production levels.

6.5 Operating Costs

Direct operating costs for the gas cleaning section of sulphuric acid plants and effluent treatment plants are outlined in Table 6.5.1-1 to 6.5.1-3. Excluded from the costs are charges for corporate overheads or debt servicing. The costs are for three levels of sulphuric acid production.

TABLE 6.4.1

CAPITAL COSTS FOR GAS CLEANING AND EFFLUENT TREATMENT PLANT AREAS FOR CASE III - DIRTY CONCENTRATE

Cost Area	$		
	600 mtpd	1000 mtpd	1500 mtpd
Gas Cleaning Area (described in Figure 3.2.3)	3,753,100	5,037,900	6,414,800
Mercury Removal Tower	930,000	1,331,000	2,448,900
Effluent Treatment (described in Figure	1,546,400	2,090,100	2,674,900
TOTAL	6,229,500	8,458,000	11,538,600

TABLE 6.5.1-1

Case I

Summary of Annual Direct Operating Costs

Cost Area		$		
		600 mtpd	1000 mtpd	1500 mtpd
Gas Cleaning Area				
Manpower:	Supervision	22,000	22,000	22,000
	Operating	64,000	64,000	64,000
	Support	8,000	9,000	10,000
Utilities:	Electrics (3¢/kWh)	178,200	297,800	445,000
	Water	1,000	1,600	4,200
	Miscellaneous	5,000	6,000	7,000
Maintenance:	(4% of capital)	119,800	262,400	204,100
Effluent Treatment Plant				
Manpower:	Supervision	22,000	22,000	22,000
	Operating	32,000	32,000	32,000
	Support	8,000	9,000	10,000
Utilities:	Electrics	58,000	98,000	147,000
	Chemicals	300,800	500,000	750,000
	Miscellaneous	4,000	5,000	6,000
Maintenance:	(4% of capital)	22,500	28,000	35,000
TOTAL		845,300	1,355,600	1,707,500
$/tonne acid		4.27	4.11	3.45

TABLE 6.5.1-2

Case II

Summary of Annual Direct Operating Costs

Cost Area		$		
		600 mtpd	1000 mtpd	1500 mtpd
Gas Cleaning Area				
Manpower:	Supervision	22,000	22,000	22,000
	Operating	64,000	64,000	64,000
	Support	8,000	9,000	10,000
Utilities:	Electrics	178,200	297,800	445,500
	Water	1,000	1,600	4,200
	Miscellaneous	5,000	6,000	7,000
Maintenance:	(4% of capital)	131,800	178,100	227,800
Effluent Treatment Plant				
Manpower:	Supervision	55,000	55,000	55,000
	Operating	160,000	160,000	160,000
	Support	10,000	12,000	14,000
Utilities:	Electrics	70,000	100,000	150,000
	Chemicals	313,800	523,000	784,500
	Miscellaneous	5,000	6,000	7,000
Maintenance:	(4% of capital)	59,000	81,200	101,900
TOTAL		1,082,800	1,514,900	2,051,900
$/tonne acid		5.47	4.59	4.15

TABLE 6.5.1-3

Case III

Summary of Annual Direct Operating Costs

Cost Area		$		
		600 mtpd	1000 mtpd	1500 mtpd
Gas Cleaning Area				
Manpower:	Supervision	22,000	22,000	22,000
	Operating	64,000	64,000	64,000
	Support	8,000	9,000	10,000
Utilities:	Electrics	178,200	297,800	445,500
	Water	1,000	1,600	4,200
	Miscellaneous	5,000	6,000	7,000
Maintenance:	(4% of capital)	187,300	254,800	354,600
Effluent Treatment Plant				
Manpower:	Supervision	55,000	55,000	55,000
	Operating	160,000	160,000	160,000
	Support	10,000	12,000	14,000
Utilities:	Electrics	70,000	100,000	150,000
	Chemicals	313,800	523,000	784,500
	Miscellaneous	5,000	6,000	7,000
Maintenance:	(4% of capital)	62,000	84,000	107,000
TOTAL		1,141,300	1,594,400	2,184,800
$/tonne acid		5.76	4.83	4.41

SECTION 7

ACID QUALITY AND CONTAMINANT REMOVAL

7.0 ACID QUALITY AND CONTAMINANT REMOVAL

7.1 Acid Quality Specifications

Analytical techniques and contaminant specifications vary widely throughout the sulphuric acid manufacturing industry[1]. An ASTM standard (E223-68) is available for analytical methods. However, most specification agreements are reached between producer and consumer for a given circumstance. Specifications for acid to be used in the production of fertilizers have not been established.

Examples of sulphuric acid specifications and typical compositions are shown in Table 7.1.1. An acid composition survey[4] of 12 U.S. metallurgical operations revealed relatively small quantities of trace element contamination. The mean values of all elements are less than 1 ppm as shown in Table 7.1.1.

A summary comparison of the contaminants in acid produced in Canada with the three cases examined in this study is shown in Figure 7.2.1.

TABLE 7.1.1

SUMMARY OF TYPICAL ACID QUALITY CONTAMINANT SPECIFICATIONS

Acid Description

Contaminant	U.S. Federal Spec. (93% H_2SO_4)([1])		Technical Grade ([1])	CIL (46)	U.S. Smelter Survey([4])		
	O-S-801C * Electrolyte	O-S-809B Technical	(U.S. Industry Typical)	(Industry Typical)	max.	min.	mean
Pb ppm	-		-	<0.1	2.8	<0.07	0.4
Zn ppm	40		-	-	1.83	0.05	0.1
As ppm	1.0	2.5	-	<0.05	0.5	0.02	0.1
Hg ppm	-			<0.05	2.3	0.003	0.05
Cd ppm	-			-	0.11	0.001	0.005
Se ppm	20			-	0.48	<0.04	0.04
Fe ppm	50	-	50-100	30	-	-	-
Cu ppm	50			0.2	0.47	<0.06	0.2
Cl ppm	-			<0.1	-	-	-
NO_3 ppm	5.0		5-20	<0.2	-	-	-
Ni ppm	1.0			0.5	1.7	0.007	0.2
Mn ppm	0.2			0.25	1.4	0.06	0.3
Cr ppm	-			0.4	3.3	0.28	0.8

*Maximum values quoted.

TABLE 7.2.1

SUMMARY OF ACID QUALITY AND CONTAMINANT REMOVAL

Operations	Acid Contaminants ppm								Acid Quality Stortcoming	
	Pb	Zn	As	Hg	Cd	Se	Cl	Fe	Description	Treatment
Falconbridge Ltd. (11) (Sudbury)	0.9		<0.05	<0.01	-		<0.05	25	Amber Colour	~0.5 kg/tonne acid of hydrogen peroxide
Inco Ltd. (Sudbury)										
Kidd Creek Smelter * (Timmins)	<1	<1	<1	0.1	-	<1	<1	5	-	-
Kidd Creek Zn Pt. (Timmins)	N/A								-	-
C.E.Z. (Valleyfield)										
Gaspe Copper (Murdochville, Que.)										
Brunswick M & S * (Belledune, N.B.)	2.1	11	0.6	0.6	0.4	0.4	<1	100	Dark Colour	None
Cominco (Trail, B.C.)										
Case I	<0.1	<0.1	<0.1	<0.1	-	<0.1	<0.1	-		
Case II	0.1	<0.1	0.4	0.1	-	0.4	0.1	-		
Case III	0.5	0.2	0.5	0.39	<0.1	0.8	0.1	-		

*telcom data

SECTION 8

CONCULSIONS

8.0 CONCLUSIONS

1. Production of acceptable commercial quality acid should be possible when smelting the types of concentrates currently treated in Canada.

2. Significant additional capital costs will be added to plant installations as contaminants in feed concentrates treated increase. The principal problem elements are fluoride, chloride, and mercury.

SECTION 9

REFERENCES

9.0 REFERENCES

A. SCRUBBER PROCESS PERFORMANCE DESCRIPTIONS

1. Kirk-Othmer, Sulphuric Acid and Sulphur Trioxide, Encyclopedia of Chemical Technology, Vol. 22, 3rd Ed., p. 190, 1983.

2. Donovan, J.R. et al., Sulphuric Acid Production from Ore Roaster Gases, J. of M. 19 (11) p. 45, Nov. 1967.

3. Schwartz, W. and Eisert, W. Examples and Limits of Air Purification in Copper Smelting Plants, Erzmetall, 1972 25, 10, p. 505-511.

4. Hedley, W.H. et al., Determination of Hazardous Elements in Smelter-Produced Sulphuric Acid, EPA-650/2-74-131, Dec. 1974.

5. Donovan, J.R. et al., Gas Purification and Sulphuric Acid Plant Design for Smelter Off-gases, presented at AIME Annual Meeting, Atlanta, Georgia, March 1977.

6. Sundstrom, O. Mercury in Sulphuric Acid, British Sulphur Magazine, January/February 1975, p. 37-43.

7. Fenco, Metallurgical Acid Plants, House file data, unpublished.

8. Steintveit, G., The Boliden-Norzink Mercury Removal Process for Purification of Roaster Gases, Lead-Zinc-Tin'80, 109th AIME, Las Vegas, 1980, p. 85.

9. Cominco Ltd, Trail Operations, published by Cominco, undated.

10. Heino K.H. et al., Fluid Bed Roasting of Zinc. Concentrate and Production of Sulphuric Acid at Canadian Electrolytic Zinc, Chapter 5, Lead and Zinc, published by AIME, N.Y., 1970.

11. Norman G.E. et al. Development and Operation of Falconbridge's New Smelting and Enviromental Improvement Process, Presented at CIM Conference, Quebec City, August 1982, p. 3-4.

12. Weisenberg I.J. et al., Design and Operating Parameters for Emission Control Studies; Kennecott, Hurley Smelter, EPA/600/2-76/036D, February 1976.

13. Weisenberg, I.J., et al., Design and Operating Parameters for Emission Control Studies, Asarco, Hayden, Copper Smelter, EPA/600/2-76-036J, February 1976.

14. Weisenberg, I.J., Design and Operating Parameters for Emission Control Studies: Phelps Dodge, Morenci Copper Studies: Phelps Dodge, Morenci Copper Smelter, EPA/600/2-76/036G.

15. Calvin E.L., et al., Inspection Manual for the Enforcement of New Source Performance Standards as applied to Contact Sulphuric Acid Plants, EPA 340/1-77-008.

16. Rastas, J., et al., Smelter Gases Yield Mercury, Chem. Eng., Vol. 78, No. 20, September 1971, p. 55.

17. Plasket, R.P., et al., Ancillary Smelter Operations and Sulphuric Acid Maintenance at Impala Platinum Limited, J. South Africa Inst. Min. Met., August 1976, p. 1.

18. Millett, H.C., Manufacture of Contact Sulphuric Acid from Arsenical Pyrites, Chem., and Ind., September 1948, p. 595.

19. Charron, R.L., Pre-acid Plant Scrubbers in the Non-Ferrous Smelting Industry, Memo from B.M. & S. to EPS Ottawa, August 1983.

20. Stankovic, G., Fluo-solids Roaster and Acid Plant at Trepea Lead and Zinc Mines and Refineries, Chapter 4, Lead & Zinc, AIME, N.Y., 1970.

21. Solar, M.Y., et al., Inco's Oxygen Flash Smelting Process for Copper and Nickel Concentrates, Off-gas Handling and Impurity Distributions. EPA 600/2-79-211, December 1979.

22. McKee Co., System Study for Control of Emissions Primary Non-Ferrous Smelting Industry, Vol. 1, 2, 3, EPA, PH86 6585, January 1969.

23. Weisenberg, I.J., et al., Design and Operating Parameters for Emission Control Studies: White Pine Copper Smelter, EPA/600/2-76/036A, February 1976.

24. Morcos, R., Effluents from Pre-acid Plant Scrubbers, Memo to C. Jose, Canadian E.P.S, August 31, 1983.

25. Rastas, J., et al., Mercury and Selenium Recovery at the Outokumpu Zinc Plant at Kokkola, Chapter 37, International Symp. on Hydromet., AIME Chicago, March 1973, p. 964.

26. Lilley, J.N., et al., Handling of Acid Slurries at the Flash Smelting Plant of the International Nickel Co. of Canada Ltd., CIMME, Vol. 44, 1961, p. 245.

27. Solar, M.Y., et al., Smelting Nickel concentrates in Inco's Oxygen Flash Furnace, 107th AIME, Denver, February 1978.

28. Inco Ltd. Impurity Distributions, Dusting and Control of Matte Grade in Inco Oxygen Flash Smelting, 50th Anniv. Mtg. of Chilean Inst. Min. Eng., November 1980.

29. Beals, G.C., et al., Copper and By-Product Sulphuric Acid Production by Palabora Mining Co., J. of M., July 1968, p. 85.

30. Rodolff, D.W. Inspiration's New Look, J. of M., July 1972, p. 14.

31. Thompson, R., History of Sulphuric Acid Production from Converter Gas at Kennecott Copper Corporation's Utah Smelter, J. of M., July 1968, p. 82.

32. Rastas, J., et al., Mercury Recovery from SO_2 - rich Smelter Gases, E/MJ, April 1971.

33. George, D.B., et al., Minor Element Behaviour in Copper Smelting and Converting, Joint AIME - MMIJ, World Min. & Met. Tech., Denver, 1976, p. 534.

34. Asahra, S. et al., Bismuth Recovery from Copper Smelting Dust, World Min. and Met. Tech., Joint MMIJ-AIME, Denver, 1976, p. 856.

35. Hargrave, J.H.D., Recovery of Fume and Dust from Metallurgical Gases at Trail, B.C., CIMJ, June 1959, p. 366.

36. Ferguson, K., Scrubbers Pre-Acid Plants, in the Non-Ferrous Smelting Industry, Government of Canada Memo, August 1983.

37. Immelman, P.D., Processing of Smelter Off-Gases for Sulphur Removal at Palabora Mining Co. Ltd., Proc. of Air Pol. 79, p. 1.

38. Brockmiller, C.A., Mercury Control for Sulphuric Acid Manufacture, World Min. Met. Tech., Joint MMIJ-AIME Mtg. Denver, September 1976, p. 795.

39. Pollution Control Permit for Cominco Ltd., B.C. Ministry of Environment, June 1980.

40. Zinc Roaster Acid Plant Design Data - Confidential.

41. Smelter X Acid Plant Design Data - Confidential.

42. Katari, V., et al., Trace Pollutant Emissions from the Processing of Metallic Ores, EPA-650/2-74-115, October 1974.

43. Uchida H., et al., Processing of Copper Smelting Gases at Naoshima Smelter, EPA-600/2-79-211, December 1979, p. 314.

44. Canadian Air Pollution Control Directorate, Air Pollution Emissions and Control Technology: Primary Copper, EPS 3-AP-82-4.

45. Smelter Y Acid Plant Design Data - Confidential.

46. Canadian Air Pollution Control Directorate, A Study of Sulphur Containment Technology in the Non-Ferrous Metallurgical Industry, EPS-3-AP-79-8.

47. Yazawa, A., et al., Distribution Behaviour of Various Elements in Copper Smelting Systems, Advances in Sulphide Smelting, Conf. Proc., AIME, San Francisco, November 1983, p. 99.

48. Itagaki, K., et al., Thermodynamic Evaluation of Distribution Behaviour of Arsenic, Antimony, and Bismuth in Copper Smelting, Advances Sulphide Smelting, Conf. Proc., AIME, San Francisco, November 1983, p. 119.

49. Kachaniwski, G. et al., Acid Plant and Converter Operation at the Mines Gaspe Smelter IBID Ref. 48, p. 749.

50. Sweeten, R.M. et al., The Kidd Smelter - Start-up and Early Operation, IBID Ref. 48, p. 789.

51. Friedman, L.J., Sulphur Dioxide Control System Arrangements for Modern Smelters, IBID Ref. 48, p. 1023.

52. Nolan, P.D., Advances in Gas Cleaning Technology, IBID, Ref. 48, p. 1040.

B. SCRUBBER EQUIPMENT GENERAL DESCRIPTIONS

53. Terry, J.P., et al., Answers to Chemical and Mechanical Problems in Gas Cleaning Systems.

54. Danielson, J.A., Air Pollution Engineering Manual, EPA No. AP-40, May 1973.

55. A.P.T. Inc., Wet Scrubber System Study, Vol. 2, EPA Rpt. R2-72-1186, July 1972.

56. A.P.T. Inc., Wet Scrubber Handbook, Vol. 1, EPA Rpt. R2-72-118, 1972.

57. Duecker W.W., et al., The Manufacture of Sulphuric Acid, Am. Chem. Soc. Mono. Series, Reinhold Pub. N.Y., 1959.

58. Gleason, T.G., How to Avoid Scrubber Corrosion, Chem. Eng. Progress, (71), No. 3, p. 43, 1975.

59. Gilbert, W., Troubleshooting Wet Scrubbers, Chem. Eng., p. 140, October 1977.

60. Brief, R.S., et al., Impingement Baffle Plate Scrubber, J. Air Pl. Con. Ass. p. 372, September 1964.

61. Anderson, R.W., et al., Cominco's Brink Plume Eliminator presented at 20th Conference of Metallurgists, Hamilton, 1981.

62. Gleason, T.G., Halt Corrosion in Particulate Scrubbers, Chem. Eng., October 1977.

63. Swemco Inc., Six Stage Scrubber Cleans Kennecott Copper Converter Gases, Swemco, N.Y.

64. Swemco Inc., Swemco Rebuilds Kennecott Scrubber, Swemco, N.Y.

65. Kirchner, R.W., Corrosion of Pollution Control Equipment, Chem. Eng. Prog., (71) No. 3, March 1975.

66. Perez, R.E., High Capacity Heat Exchangers Conserve Water, Chem-Process, Mid-Novemebr 1977, p. 102.

67. Imperato, N.F., Gas Scrubbers, Chem. Eng., October 1968, p. 152.

68. Seiler, E., Venture-Type Wet Scrubbers Air Cond., Ht. and Vent., July 1968, p. 14.

69. Norman, W.S., The Performance of Grid-Packed Towers, Trans Inst. Chem. Engs. 29 1951, p. 227.

70. Lapple, C.E., et al., Performance of Wet Dust Scrubbers, Chem. Eng. Prog., March 1955, p. 110.

71. Harris, L.S., The Ejector Venturi Scrubber, Chem. Eng. Prog., 60 No. 5, May 1964, p. 100.

72. MacDonald, B.I., An Operator's View of Scrubber Collectors, Conference Proc. Design Operation and Maintenance of High Eff. Part. Conf. Eng., St. Louis, March 1973.

73. Jones, W.P., A Venturi Scrubber for Cleaning Industrial Gases, Ht. and Vent., April 1951, p. 73.

74. Borenstein, M., Air Pollution Control in Non-Ferrous Metallurgical Ind., Ht., October 1967, p. 1866.

75. Morash N., et al., Removing Solid and Mist Particles from Exhaust Gases, Chem. Eng. Prog. 63, No. 3, 1967, p. 70.

76. Harris, L.S., Fume Scrubbing with the Ejector Venturi System, Chem. Eng. Prog. 62, No. 4, 1966, p. 55.

77. Bonn, D.E., Wet Type Dust Collectors, Chem. Eng. Prog. 59, No. 10, October 1963, p. 69.

78. Calvert, S., How To Choose a Particulate Scrubber, Chem. Eng., August 1977, p. 54.

79. Stairmand, C.J., Removal of Grit, Dust and Fume from Exhaust Gases from Chemical Engineering Processes, Chem. Engineering, December 1965, p. CE 310.

80. Calvert, S., Upgrading Existing Particulate Scrubbers, Chem. Eng., October 1977, p. 133.

81. Brady, J.D. Venturi Scrubbers, Air Pl. Design Handbook, Part II, M. Dekker N.Y., 1977, p. 747.

82. Phillips, M.D. , Countercurrent Contact Wet Scrubbing, Air Pol. Design Handbook, M. Dekker N.Y., 1977, p. 721.

83. Klugman, W., The Ionizing Wet Scrubber, Air Pol. Design Handbook, M. Dekker N.Y., 1977, p. 721.

84. MacDonald, J.W., Packed Wet Scrubbers, Air Pol. Design Handbook, M. Dekker N.Y., 1977, p. 699.

85. Borenstein, M., Special Construction Materials for Scrubbers, Air Pol. Design Handbook, M. Dekker N.Y., p. 949.

86. Calvert, S., Entrainment Separators for Scrubbers, EPA-650/2-74-1 19B, August 1975.

87. NTIS Bibliography of EPA Publications Gas Scrubbers Used On Pollution Control, 1979-April 1981, PB81-805947 May 1981.

88. NTIS Bibliography of the Engineering Index Data Base, Gas Scrubbers Used in Pollution Control, 1979-April 1982, PB81-805954.

89. Biales, G.A., How to Pack a Column, Chem. Eng. Prog., 60, No. 10, October 1974, p. 71.

C. SCRUBBER DESIGN OUTLINES

90. Calvert, S., Engineering Design of Fine Particle Scrubbers, Journal of the Air Pollution Control Association, October 1974, p. 929-934.

91. Bonilla, C.F., Air Humidification Coefficients in Spray Towers, Ind. and Eng. Chem., (42) No. 12, December 1950, p. 2521.

92. Behie, S.W., and Beeckmans, J.M., Effect of Water Injection Arrangement on the Performance of a Venturi Scrubber, Journal of Air Pollution Control Association, October 1974, p. 943-945.

93. Boll, R.H., Particle Collection and Pressure Drop in Venturi Scrubbers, Ind. Eng. Chem. Fundam. 12, No. 1., 1973, p. 40.

94. Narsimham, G., Determination of Economic Gas Velocity for Plate Absorbers, Chem. and Proc. Eng., 43, Dec. 1962, p. 620.

95. Bettelheim, J., et al., Fundamental Correlations for the Calculations of Spray Absorbers, Int. Chem. Eng., 4, No. 4, October 1964, p. 565.

96. Liimatainen, R.C., et al., Removal of Halogens Carbon Dioxide and Aerosols from Air in A Spray Tower, Air Pol. Cont. Ass. J. 6, No. 1, May 1956, p. 17.

97. Kalika, P.W., How Water Recirculation and Steam Plumes Influence Scrubber Design, Chem. Eng., July 1969, p. 133.

98. Semrau, K.T., Dust Scrubber Design - A Critique on the State of the Art, Air Pol. Conf. Ass. J., 13 No. 12, December 1963, p. 587.

99. Semrau, K.T., Practical Process Design of Particulate Scrubbers, Chem. Eng., September 26, 1977, p. 86.

100. Bhatia, M.V., Packed Tower and Absorption Design, Air Pol. Cont. Design Handbook, Vol. 2, pub. by M. Dekker Inc., N.Y., p. 609.

101 Calvert, S., Wet Scrubber Handbook, NTIS Publication PB213016, August 1972, Chapter 5.

D. ECONOMICS OF SCRUBBER INSTALLATIONS

102. Mathews, J.C., et al., SO_2 Control Process for Non-Ferrous Smelter, p. 281, EPA-600/2-76-008, January 1976.

103. Hanf, E.W., Economic Evaluation of Wet Scrubbers, Chem. Eng. Prog. (71) No. 3, March 1975.

Previous Noted Reports With Economic Related Data

Ref. 52 p. 1050.

E. SCRUBBER EFFLUENT TREATMENT

104. Habashi, F., Metallurgical Plants: How Mercury Pollution is Abated, Enviro. Sc. and Tech. 12, No. 13, December 1978, p. 1372.

105. Mullen, H., Converting Scrubber Sludge and Flyash into Landfill Material, Poll. Eng., May 1978, p. 71.

106. Sulphuric Acid Manufacturing, Air Pollution Eng. Manual, EPA, AP-40, May 1973, p. 716.

107. I.B.I.D., Ref. 106, p. 716.

108. Marchant, W.N., Selenium Removal from Acidic Waste Water Using Zinc Reduction and Lime Neutralization BOM RB312, 1978.

109. Murao, K., et al., Recovery of Heavy Metals from the Waste Water of Sulphuric Acid Process in Ashio Smelter, World Min. & Met. Tech. Joint MMIJ-AIME, Denver 1976, p. 808.

110. Greber, J.S., et al., Assessment of Environmental Impact of the Mineral Mining Industry, EPA-600/2-79-107, p. 155.

111. Coleman, R.T., et al., Sources and Treatment of Wastewater in the Non-Ferrous Metals Industry, EPA-600/2-80-074, p. 83.

112. Mohri, E., et al., Recovery of Metals from the Dusts of a Flash Smelting Furnace, World Mining & Metals Tech., Joint MMIJ-AIME Mtg. Denver 1976, p. 520.

113. P.E.D. Co. Environmental, Inc., Industrial Process Profiles for Environmental Use, Chapter 29, Primary Copper Industry, EPA-600/2-80-170, July 1980, p. 714.

114. Weir, A., et al., Factors influencing Plume Opacity, Env. Sc. and Tech., 10, No. 6, June 1976, p. 539.

F. SMELTING PROCESS INFORMATION

115 Southern Research Institute, Performance Evaluation of an Electrostatic Precipitator Installed on a Copper Smelter Reverbatory Furnace, EPA-600/2-79-119, June 1979.

116 Schwitzgebel K. etal., Trace Element Study at a Primary Copper Smelter Vol. II, EPA-600/2-78-0656, March 1978.

117 Johnson R.E., Copper and Nickel Converters AIME Symposium, New Orleans, February 1979.

APPENDIX A

SCRUBBER DESIGN REFERENCES

APPENDIX A

SCRUBBER DESIGN REFERENCES

The main purpose of this study is to outline the expected behaviour of contaminants produced in metallurgical operations which outfall as acid plant effluent.

However, during the literature search carried out as the initial step in the program, many references relating to the design and operation of scrubbers were collected. The more important books and articles have been noted as follows:

A.1 The opus magnum in this area is the Scrubber Handbook[56] commissioned by E.P.A. Aspects of scrubber design, operation, and costing are discussed. Its only shortcoming is its publication date of 1972. A second volume[55] outlines the vast reference collection for the work. The principal author also published follow up articles (78, 80, 86, 90)

A.2 Another general handbook produced by the EPA is the Air Pollution Engineering Manual which covers gas cleaning technologies established in the early 1970's.

A.3 A series of articles produced by Swemco New York (58, 62, 63, 64) on scrubber design and corrosion are informative.

A.4 More recent scrubber design data is available in various chapters in the "Air Pollution Design Handbook" noted in references 81, 82, 83, 84, 85 and 100. The publication is in two volumes.

A.5 Bibliographies on gas scrubbing were put together by the U.S. National Technical Information Service (87, 88) covering the Engineering Data Base and EPA publications released from 1979 to 1981.

A.6 Additional information related to the design and operation of scrubbers can be found in references Nos. 52 to 101.

APPENDIX B

AMERICAN NON-FERROUS SMELTER ACID COMPOSITION

APPENDIX B

AMERICAN NON-FERROUS SMELTER ACID COMPOSITION

Discussion of acid quality in Section 7 refers to a review of contaminants in acid produced in twelve American metallurgical operations. Table B-1 shows the impurity element data. Aveaged values from Table B-1 are presented in Table 7.1.1.

TABLE B-1

AMERICAN NON-FERROUS SMELTER SULPHURIC ACID ANALYSES
ppm by wt.

Trace Element	Tacoma Cu Smelter	Hayden Cu Smelter	El Paso Cu Smelter	Corpus Christi Zn Smelter	Columbus Zn Smelter	City Service Cu Smelter	St. Joe Lead	N.J.Z. Zn Smelter	Missouri Lead	Nat. Zinc Zn Smelter
As	0.44	0.08	0.5	0.13	0.03	0.02	0.02	0.12	0.02	0.03
Cd	<0.005	NA	NA	0.01	<0.005	0.001	0.11	0.017	0.002	0.005
Cu	0.20	0.28	0.1	0.06	0.07	0.13	0.47	0.11	0.36	0.14
Fe	51	32.3	8.	11.5	24.2	9.	167.	22.	124.	37.
Hg	0.003	0.010	0.003	0.20	0.16	0.046	0.029	0.056	0.009	2.28
Mn	0.25	0.38	0.06	0.11	0.15	0.15	1.35	0.24	0.76	0.28
Ni	0.15	0.48	0.10	0.07	0.08	0.11	1.63	<0.11	1.68	0.18
Pb	0.25	1.6	1.0	0.27	<0.07	0.33	2.78	0.38	0.48	<0.13
Sb	0.18	<0.01	<0.1	<0.05	0.12	0.012	0.032	0.01	0.018	0.003
Se	<0.004	0.04	0.06	0.48	<0.04	<0.02	NA	<0.02	<0.02	0.17
Zn	0.06	0.94	0.84	0.14	0.11	0.05	0.04	1.83	0.1	0.07

APPENDIX C

HOT ELECTROSTATIC PRECIPITATOR PERFORMANCE

APPENDIX C

HOT ELECTROSTATIC PRECIPITATOR PERFORMANCE

Estimates of recovery of various dusts and fume were necessary to predict the expected scrubber dust loading in the three cases investigated.

Fair agreement on expected recoveries in an E.S.P. are shown in Table C-1 for materials which behave like dust particulate. As materials become fume like (i.e less than 2μ in diameter) the behaviour is less predictible. Recoveries of arsenic, mercury, and selenium show the greatest uncertainty.

TABLE C

SUMMARY OF IMPURITY ELEMENT RECOVERIES IN HOT ELECTROSTATIC PRECIPITATORS

Element	% of Element in Inlet Recovered			
	Hayden (115) Smelter	U.S. (116) Smelter	INCO	This Study
As	38	16	15	15
Pb	97	100		97
Hg	30	1.5		15
Cd	96	100		96
Se	97	18		60
Cl	-	-		10
F	2	0.4		2
Sb	92	100		92
Cu	98	100		98
Fe	98	-		98
Zn	90	100		97
Sulphides/ Sulphates				98
Gangue				98